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The social functions of science

War-time advances in applied scientific research, of which the development of atomic energy is only one manifestation, have at length opened the eyes of the average man to the fact that, for good or ill, science has become a dominant factor in the daily lives of all the peoples of the world. The governments of the United Nations are rightly paying much attention to the future role of science and scientists in national life, and important decisions are likely to be made during the coming months. It would be regrettable if the present preoccupation with problems relating to the release, control, and employment of atomic energy were allowed to obscure the urgent need for reviewing the future of science as a whole. Of equal urgency is the need that this review should be conducted, as far as is humanly possible, in an atmosphere free from political prejudice and expediency: the commonplace that 'science knows no frontiers' has now become fraught with keener and more imminent significance.

Many recent discussions on the social functions of science will be found on analysis to have dealt with a more specialized subject, namely the social functions of applied science; and that is only a part of the problem. In this issue we publish an article by Mr E. F. Caldin which makes a thoughtful and objective contribution to the question as a whole. In particular, Mr Caldin makes a clear distinction between fundamental scientific research, applied research, and technology. It is perhaps not generally realized outside scientific circles that the war-time progress of science has been made almost entirely in the applied field, and that we have, as it were, been living on our capital knowledge. Comparatively few advances in scientific knowledge of a fundamental kind were made during the years of war. If the recent high rate of advance in applied science is to be maintained, there is a pressing need for a return to the programme of fundamental research, which university laboratories are particularly well adapted to pursue, and in which many of the great industrial corporations are now with welcome vision taking a very active and fruitful share.

Failure to recognize the vital service of fundamental research, by which is meant the investigation of natural phenomena with indifference to utilitarian ends, underlies the vociferous demands made in various quarters for the governmental control of research. Such control would to a large extent defeat its avowed object; for who can issue directions for an untravelled path leading to an unknown destination? Direction is practicable only in the fields of applied science and technology, where the problem is to apply existing knowledge to the satisfaction of specific requirements. This kind of research is undertaken largely in industrial laboratories, and is of course ultimately orientated by considerations of supply and demand. Its full development depends upon the existence of a large reserve of previously unexploited knowledge, the provision of which is one of the functions of fundamental research. The atomic bomb is often quoted by the advocates of control as a shining example of scientific progress under central direction; but in point of fact all the principles on which the bomb is based were firmly established before the war by individual scientists, or small teams of scientists, seeking only to explore new fields of knowledge.

The necessity for the maintenance and encouragement of unfettered fundamental research raises an associated problem of general interest and importance, namely the financial status of scientists. There are very few industries in the world which do not depend to some extent upon the fruits of scientific research, and many which are almost completely dependent. Witness, for example, the electrical, petroleum, coal, steel,

chemical, and textile industries: and these, under modern conditions, owe as great a debt to the academic research worker as to the applied research worker within the industries themselves. Yet the fact is indisputable that the university scientist receives, on an average, very considerably less financial reward than his industrial counterpart of comparable ability. Furthermore, the industrial scientist himself, as long as he remains at research work, is usually ill paid in comparison with his administrative colleagues. The result is that throughout the world a financial temptation exists tending to attract academic scientists into industrial research and thence to administration. For the good of science, of industry, and of society in general, this continuous and damaging drain of valuable potential should be greatly lessened: not by governmental coercion, but by more adequate financial recognition of the value of both pure and applied research. The great majority of scientists place their work first and are not moved by avarice; but if they are to give of their best they must be freed from constant financial anxiety and afforded the means to live at the level of their social peers. There are few countries, if any, where such a state of affairs exists at present. Attempts at betterment must, however, be ever watchful of control. Within the sphere of fundamental research it is essential that the worker should be entirely free to follow his own bent. Had 'direction' been applied to the great scientists of the past—men like Newton, Galileo, Pasteur, Rutherford—they would no doubt still have done distinguished work, but the world with equal certainty must have been the poorer by some of their most far-reaching discoveries.

The fact has already been stressed that a wider interpretation to the public of the nature and meaning of science is a necessary preliminary to the general recognition of the importance of the scientist in world affairs. With the return of large numbers of scientists from war work to their normal activities, the moment is opportune to repeat the emphasis. Unfortunately, though the interpretation of science must come mainly from scientists themselves, few have been sufficiently interested to essay it, and fewer still have shown themselves competent to do so. But now, when atomic energy warns us that we have entered a new and uncertain era, it is the plain duty of the scientist to place the interpretation of science to the public on the same level of urgency as the actual advancement of knowledge. Even from the narrower point of view of the future of science itself this education of the body politic must be undertaken; for it is to a large and growing extent the general public which in the last resort foots the bill for scientific research, and in order to maintain present support and to seek for a future substantial increase it is right that those most concerned—the scientists themselves—should attempt to make their fellow citizens understand as much as possible of the spirit and results of science. In particular is this necessary for securing the increased support vitally required for fundamental research. The results of applied research, as demonstrated in the radio, telephone, internal combustion engine, aeroplane, and so on, more or less speak for themselves; the essential function of fundamental research is, however, far more difficult to understand, and especial pains should therefore be taken to make its importance clear to everyone. There is no lack of excellent publicity media, capable of reaching every section of the people; and by co-operation between scientists and those directly concerned with these media much valuable work could be done for the public good and for the advancement of science. A central publicity board and information bureau for science would be a governmental finger that no scientist would mind seeing in the scientific pie; but Providence helps those who help themselves, and it is to be hoped that scientists—especially the younger of them—will address themselves with vigour to this important task of interpreting science to others.

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Britain's geological history

O. M. B. BULMAN

For so small a country, Great Britain is unique in the completeness of its geological record. It is therefore not surprising that the foundations of geological science were laid here. Dr Bulman's lucid interpretation of the geological map of Great Britain ably illustrates the truth of the geological principle, established by James Hutton in 1788, that 'the earth may be considered as an organized body . . . in which the necessary decay is continually being repaired in the exertion of those productive powers by which it has been formed.'

In reality, land surfaces have little of that permanence with which they are endowed in the minds of most of us. Rather are they regions of unavoidable decay, where various processes of weathering are steadily breaking down the rocks to sands and muds; and rivers, those almost universal agents of transport, are carrying away the detritus to its ultimate resting-place on the floor of the ocean. That stratified rocks are the sands and muds of bygone ages and have been thus formed out of the erosional debris of pre-existing land-masses began to be appreciated at the end of the eighteenth century, when Hutton could write of 'a system in which old continents are wearing away, and new continents forming in the bottom of the sea.' This recognition brought with it the realization that in their original order of superposition we have the clue to the relative ages of our sedimentary rocks; and on that simple truth rests the whole scientific study of historical geology.

Geological time is vast in relation even to such slow processes as weathering; hills and valleys, against such a time-scale, are but the expression of a passing phase in the smoothing down of a continent to a low-lying, featureless plain. Land cannot for long remain much above sea-level, and the shallower ocean basins will become choked with sediment, unless the earth's crust is in some way thrown into fresh relief. The occurrence in high mountain ranges of sedimentary rocks bearing marine fossils itself implies changes of sea-level so great that uplift of the land is the only rational explanation of the phenomenon.

We still know relatively little of the causes of this rejuvenating crustal movement, which (in Playfair's striking phrase) maintains continuity of superficial processes by 'making the decay of one part subservient to the restoration of another.' In general terms, there must be periodic adaptations of the outer crust of the earth to the cooling and shrinking interior; but other factors are certainly involved as well. Such spasms varied in severity, sometimes involving intense folding of the rocks together with faulting (or displacement along planes of fracture), sometimes a hardly measurable distortion; but always they have left evidence through the geological record in the form of breaks in the rock sequence. One of the outstanding contributions of that great pioneer, James Hutton, was his recognition of the geological significance of these physical breaks or unconformities, where newer strata rest upon the eroded edges of an older series. Though greatly in advance of his times, as long ago as 1788 Hutton saw earth history as a succession of upheavals and erosion, alternating with relatively quiescent periods of sedimentation.

Geologically, Britain has been fortunate in having spent so great a part of geological time to seaward of an unstable continent. On balance, submergence has surpassed emergence, deposition has exceeded erosion, and a nearly complete sequence of rocks has been the reward. Indeed, the variety and completeness of our record of the 500 million years or so since life began on this planet is probably, for the size of our country, unique. It is therefore not altogether surprising that the foundations of the study of historical geology were laid here. Of the fourteen systems into which geologists have divided the stratified rocks of the world, only one is missing from our island.

THE GEOLOGICAL MAP OF BRITAIN

A standard geological map depicts so far as possible the known distribution of rocks immediately below the superficial deposits of soil and 'drift,' with colouring or shading to distinguish them according to their age rather than their character. This of itself affords a clue to their inclination and structure, for except as a result of extreme disturbance, the older must underlie the newer. A three-dimensional concept is thus

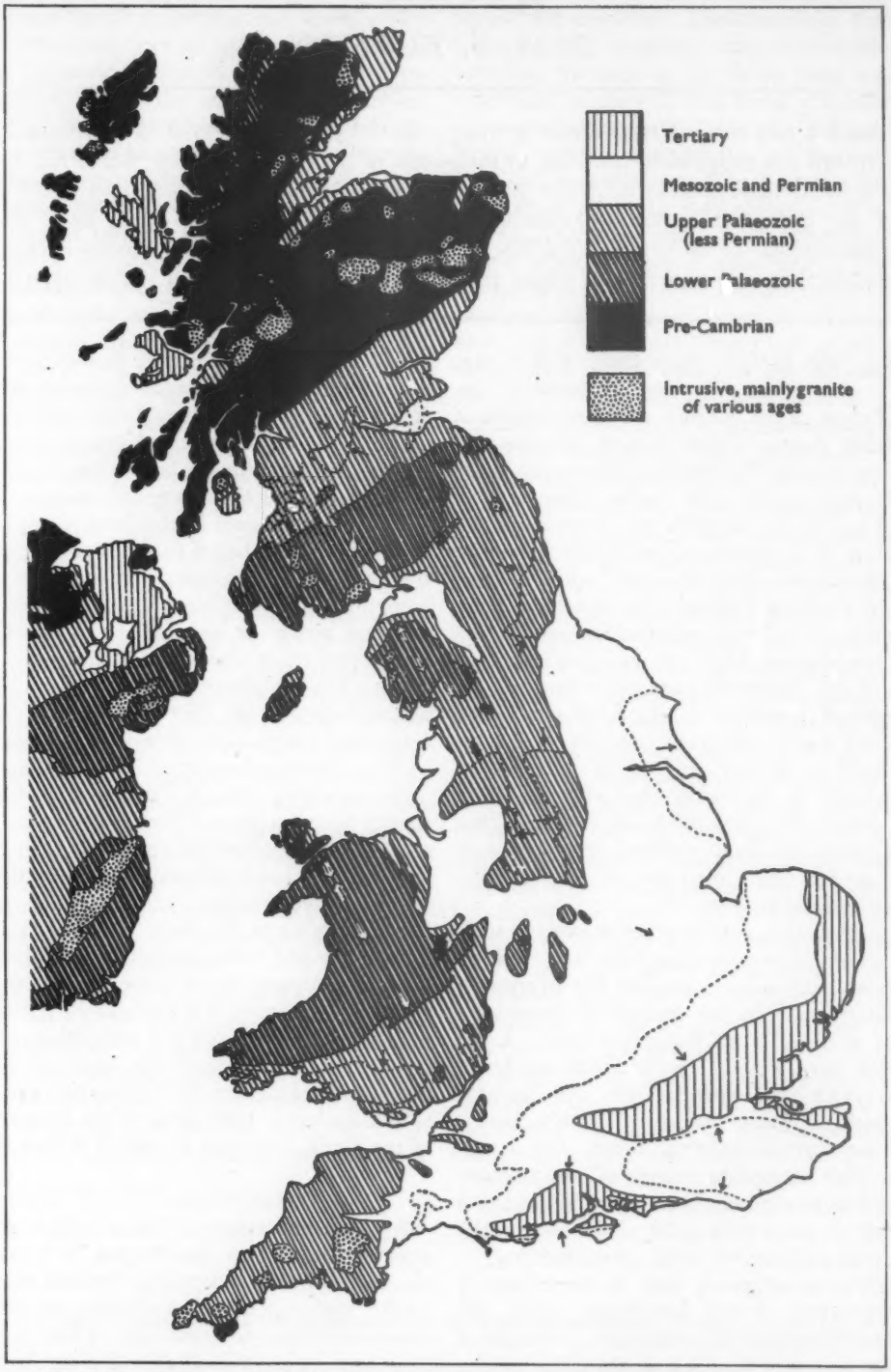

FIGURE 1 – *Simplified geological map of Britain showing the rocks that would appear at surface on removal of the soil and Quaternary (Ice Age) deposits. The highest Palaeozoic system, the Permian, is often classed with the overlying Triassic system as the New Red Sandstone, and outcrops of Permian have here been included with the Trias in the Mesozoic division. Approximate regional dip or inclination of the strata is indicated by the arrows.*

introduced unobtrusively—the surface distribution reflects an underlying structure. In *making* a geological map, the geologist must express two-dimensionally his conclusions regarding three-dimensional structure, and in *reading* a map he interprets in depth what is presented to him in plan.

Though today situated off the north-western margin of the continent of Europe, Britain has a structural tilt towards the south-east, and for the greater part of her geological history a considerable land-mass lay away to the north and west. Erosion of this now-vanished continent produced much of the detritus which went to make our sedimentary rocks. It is for convenience sometimes referred to by geologists as 'Atlantis,' but its final disappearance must long have preceded the advent of man and his legends. As a result of this persistent structural tilt, however, the oldest rocks are now exposed at the surface in north and north-west Britain, and travelling south-eastwards we are, in general, passing over the edges of successively newer strata bevelled by erosion.

FIGURE 2 – *Key to British place names mentioned in the text.*

Outcropping to the north and west of Scotland and Ireland, with minor exposures projecting apparently haphazard here and there through the cover of newer rocks in Wales, central England, and Cornwall, are the ancient crystalline and sedimentary rocks of the pre-Cambrian, antedating the earliest life of which we have undisputed fossil evidence. These form in themselves a complex succession, representing an interval of time estimated at more than 1,000 million years, and still they do not include anything recognizable as the original crust of the solidifying earth. Here however, we may consider them simply as forming the compact floor underlying the newer, fossiliferous strata.

On this compact formation lie next in order the Palaeozoic[1] (or primary) rocks, outcropping over most of the area between the Scottish and Irish pre-Cambrian and a line drawn from the mouth of the Tees to Start Point in Devon. These rocks are divided into six geological systems, three in the Lower Palaeozoic and three in the Upper, together representing some 300 million years. The upper and lower divisions are separated by an unconformity, marking a period of intense earth movement; the Lower Palaeozoic rocks were much contorted and eroded before becoming buried under newer Palaeozoic strata. Towards the end of Upper Palaeozoic times—between the Carboniferous and Permian systems—there was another such episode, less violent, but again followed by extensive erosion. For simplicity, on the accompanying map and in the account which follows, the Permian system has been included with the overlying Mesozoic[2] division, so that the horizon of this second great unconformity is thus made to coincide with the Palaeozoic/Mesozoic boundary.

Upon these two great superimposed layers of folded and eroded Palaeozoic strata the Mesozoic (or secondary) rocks rest, together representing a period of about 120 million years. They form a more superficial layer, tilted gently to the east and south-east. The regularity of their regional eastward dip is interrupted by two structural depressions, the London and Hampshire

[1] Gr. *palaeos*=old, *zoe*=life.
[2] Gr. *mesos*=middle, *zoe*=life.

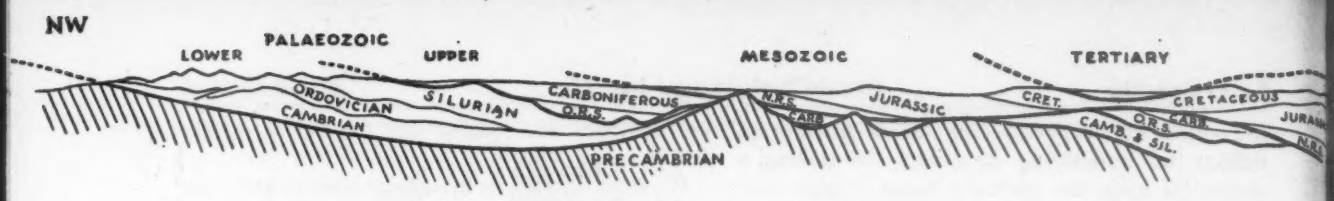

FIGURE 3 – *Schematic section from North Wales to the Weald, summarizing the depositional relations of the sedimentary rocks. Vertical scale (and hence dips and thicknesses) greatly exaggerated, especially in the south-east.*

Basins, in which remnants of the youngest or Tertiary rocks (deposited during the last 50 to 60 million years) have so far survived the erosion of the present terrestrial phase. These two shallow basins, with the anticline of the Weald arching-up between them, owe their formation to that mid-Tertiary period of disturbance which on the mainland of Europe gave rise to the Alps and the mountain arcs of the north Mediterranean regions.

There are innumerable lesser unconformities throughout the succession, some due to temporary uplift, and others even to no more than a local silting-up of the sea-floor; but these are the major divisions into which earth movement has separated the geological column in this country. Their relations are shown diagrammatically in figure 3; to understand them more fully, we may examine and strip away certain of the successive layers, before reconstructing the history of events which they reveal.

THE QUATERNARY ROCKS

Pleistocene

Removing the superficial layer rather vaguely referred to as 'soil,' we should still find an extensive mantle of boulder-clay and unconsolidated sands and gravels that owe their origin directly or indirectly to the melting of the ice-sheets which overspread so much of Britain during the Great Ice Age. Such deposits are so widespread and superficial that, like the still more recent soil and alluvium, they are omitted altogether from the 'solid' map.

THE TERTIARY ROCKS

Pliocene (*above*)
Miocene (*absent in Britain*)
Oligocene
Eocene (*below*)

Sediments of Tertiary age are practically confined to the London and Hampshire Basins of south-east England (figure 1). Parts of a once continuous sheet, they have become separated through erosion of the crest of the complementary Weald anticline. The sediments are shallow marine or estuarine in character, with some freshwater beds appearing towards the west, and must have been deposited in a shallow sea which probably at no time extended far beyond their present west and north-west boundary. Most of Britain to the north-west was probably dry land, and in this direction rocks of Tertiary age are not found again until we reach the north of Ireland and the Western Isles of Scotland, where they are of strikingly different character. Here occur extensive remains of Tertiary lava flows, poured out over a land surface of pre-Cambrian, Palaeozoic, and Mesozoic rocks, with a few intercalated dirt-bands or fossil soils containing the plant remains by which their early Tertiary age has been established.

Tertiary rocks of south-east England rest everywhere with slight unconformity upon an eroded surface of Chalk, the highest Mesozoic formation, indicating that a brief land period must have separated the Mesozoic and Tertiary eras in this country as over most of Europe. The contact is visible round the margins of the present basins and is encountered in all of the many wells sunk through these formations. To remove the Tertiary rocks would be to find this whole area surfaced by Chalk, as shown in figure 5(*a*).

THE MESOZOIC ROCKS

Cretaceous (*above*)
Jurassic
Triassic (Permian) } New Red Sandstone (*below*)

It might be supposed that, continuing this peeling process downwards through the superposed layers on the Mesozoic, we should uncover successive surfaces likewise continuous over south-east England. Instead, however, deep borings through the Tertiary and Upper Cretaceous rocks of the London Basin pass, not into Lower Cretaceous or even into Mesozoic rocks, but abruptly into Palaeozoic strata; and if for the next layer we stripped away all the Upper Cretaceous rocks we should meet with the unexpected distribution shown approximately in figure 5(*b*). There is thus revealed a fossil plateau, whose existence would be entirely unsuspected from surface evidence alone, over which all but the highest Mesozoic rocks are absent and against whose sloping sides these earlier Mesozoic rocks all thin out. The varying thickness of the formations involved,

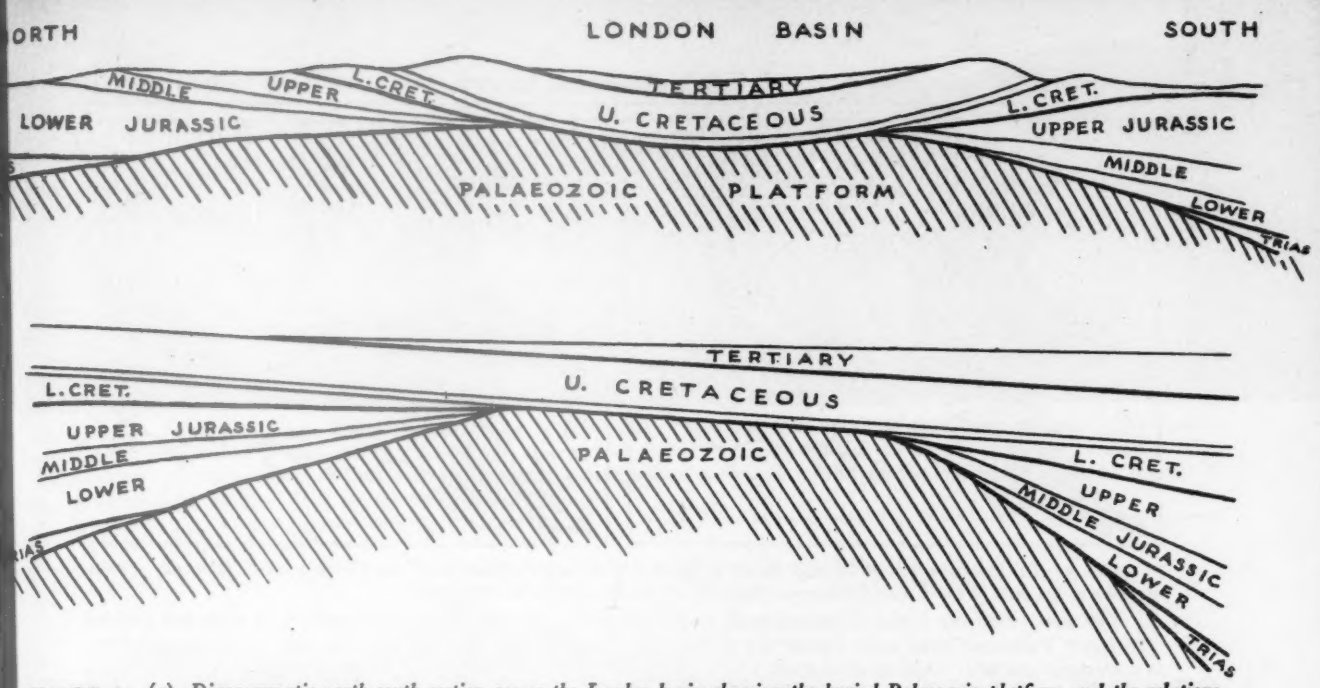

FIGURE 4 – (*a*) *Diagrammatic north-south section across the London basin showing the buried Palaeozoic platform and the relations of the various divisions of the Mesozoic.*

(*b*) *The same, eliminating the Tertiary folding. This brings out more clearly the fact that the Palaeozoic platform stood up as a land area against the shores of which the Lower Mesozoic rocks were deposited. In both sections the inclinations of the strata have been greatly exaggerated.*

determined from bore-holes, enables us to construct the section shown in figure 4 (*a*); and from this it becomes clear (straightening out the Tertiary folding as in figure 4 (*b*)) that this Palaeozoic platform under south-east England must have stood up as a persistent land-mass throughout the greater part of Mesozoic time. Looked at another way, the boundary shown in figure 5 (*b*) approximates to the eastern coastline of the Jurassic and Lower Cretaceous seas. Here is evidence of the irregularity of the surface upon which the Mesozoic rocks were laid down—an irregularity probably accentuated by renewed movement and periodic uplift during the Mesozoic era.

Forming the base of the Mesozoic strata are the reddish marls, sandstones, and pebble beds of the Trias system which, together with the underlying Permian system, are conveniently grouped together as New Red Sandstone. These deposits accumulated in the more low-lying regions between the mountainous massifs of the north and west, and the now-buried Palaeozoic platform to the east.

THE UPPER PALAEOZOIC ROCKS

Carboniferous (*above*)
Devonian (=Old Red Sandstone) (*below*)

The unconformity between the New Red Sandstone of northern England and the folded Carboniferous rocks below is perhaps the most striking in all Britain. It is also the most fully explored, in the development of the economically important coalfield areas.

Carboniferous rocks occupy the greater part of the area shaded Upper Palaeozoic in figures 1 and 13, sometimes separated from the outcrop of older rocks by a strip of Old Red Sandstone, but often overlapping this to rest directly upon islands and massifs of older rock (Lower Palaeozoic, e.g. figure 8, or pre-Cambrian). Stripping away the Mesozoic strata, the area occupied on the map by Upper Palaeozoic, and in particular by Carboniferous rocks, would be very greatly increased; and indeed the Coal Measures of the Upper Carboniferous are worked under a Mesozoic cover over much of the Midlands and the coalfield regions east of the Pennines. But again, not the whole surface thus exposed would be formed of Upper Carboniferous rocks, partly because there are regions where these rocks were never deposited, chiefly because in others again they were eroded away from the crests of folds before the deposition of the Mesozoic rocks. Three large synclines preserved Coal Measures from erosion at the end of the Carboniferous in the now half-exposed and half-concealed coalfields of Durham, Yorkshire-Nottinghamshire, and Lancashire. To the south

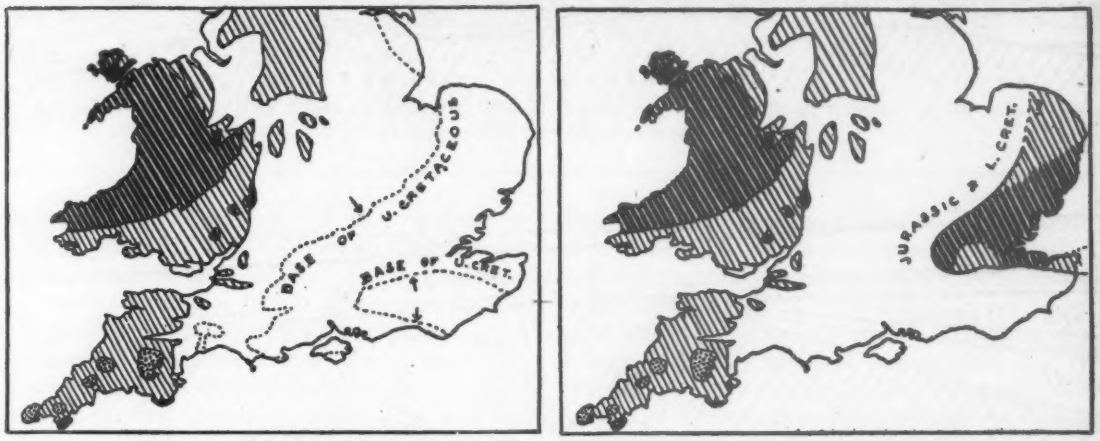

FIGURE 5 – (*a*) *Southern part of the map shown in figure* 1 *as it would appear with the Tertiary strata removed. Present outcrops of the base of the Upper Cretaceous shown by the broken line in the Mesozoic.*
(*b*) *The same, with the Upper Cretaceous rocks removed, revealing the buried Palaeozoic platform of south-east England. The Upper Palaeozoic rocks under London are of Old Red Sandstone age; but in East Kent, Coal Measures are worked in a concealed coalfield. Shading as in figure* 1.

of the Pennines, a complex fan of structure-lines beneath the Trias determines and separates the various Midland coalfields. Carboniferous rocks are absent from much of the southern Midlands and eastern England, but reappear under the Mesozoic of East Kent and in the semi-exposed Bristol coalfield. The nature of the whole surface forming the floor of the Mesozoic is difficult to predict, because of the rarity of deep borings away from the productive coalfield areas, but some of the known 'snags' or islands of older rock are shown in figure 13, together with the approximate outlines of the known Coal Measure basins.

At the base of the Carboniferous, the Old Red Sandstone occupies extensive pockets in the irregular surface which resulted from the intense 'Caledonian' mountain-building movements at the end of the preceding Lower Palaeozoic era.

THE LOWER PALAEOZOIC ROCKS

Silurian (*above*)
Ordovician
Cambrian (*below*)

Stripping away the Upper Palaeozoic strata would disclose a complex zone of folded and faulted Lower Palaeozoic rocks trending obliquely across Britain, with a belt of pre-Cambrian separating the main Lower Palaeozoic tract of England, Wales, and south Scotland from that of the north-west Highlands. But we do not yet know to what extent the pre-Cambrian would also appear under the Upper Palaeozoic of the Midlands and eastern England. We know of peaks of pre-Cambrian projecting here and there through the cover of Upper Palaeozoic to appear on the Mesozoic floor; on the Upper Palaeozoic floor (revealed by removing the Upper Palaeozoic) their number would surely be greater, and there might well be some relatively large areas of pre-Cambrian. From the characters of the Lower Palaeozoic sediments, we are led to believe that such areas may have occurred in the Irish Sea off the North Wales coast, and over Lancashire; perhaps also in the foundations of the Pennines. Or these and others may have received a thin covering layer of Upper Silurian rocks. A few deep boreholes in eastern England have penetrated to pre-Cambrian rocks in areas where the Upper Palaeozoic is thin or absent (page 51); but this costly exploratory boring is something that geologists hope may one day be undertaken at properly selected sites for its scientific value alone.

THE GEOLOGICAL HISTORY OF BRITAIN

These discontinuous layers of rock shown on the geological map record a sequence of changing geographies and climates which we may now attempt to trace in outline.

The end of the pre-Cambrian era must have witnessed a widespread retreat of the sea and extensive erosion, and in Britain, as elsewhere, the Palaeozoic era begins with a conspicuous marine regression. The pre-Cambrian rocks of the Grampians and Ross and Cromarty

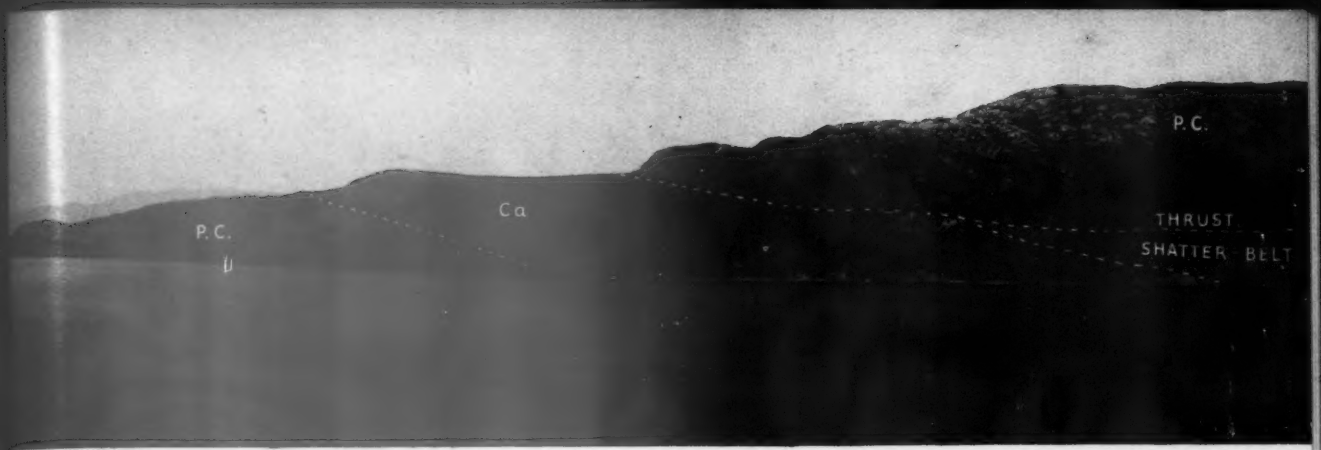

FIGURE 6 – *View across Loch Glencoul, in the north-west Highlands of Scotland. The crystalline pre-Cambrian 'gneiss' (P.C.) in the upper half of the picture, to the right, has been thrust almost horizontally over gently-dipping Cambrian shales and quartzites (Ca), which rest unconformably on the pre-Cambrian (P.C.) forming the headland to the left. Underlying the thrust to the right is a shatter-belt of faulted rocks forming the 'sole' of the thrust-mass.*

(Geological Survey photograph (Crown copyright reserved) to which have been added ink-lines indicating the approximate position of thrust-plane and unconformity.)

FIGURE 7 – *The Isle of Staffa, off Mull, an eroded remnant of the volcanic plateau of Western Scotland. The basaltic lava flows have developed shrinkage-cracks on cooling, and the lower flow in this figure shows very regular prismatic or columnar jointing. From a diorama in the Geological Museum, London.*

(Geological Survey photograph (Crown copyright reserved).)

URE 8 – *Eglwyseg Mountains, north of Llangollen. Carboniferous stone forming the bold escarpment rests unconformably on Lower eozoic shales and flagstones of Upper Silurian age. The precise contact dden under scree and talus, but Silurian flagstones litter the fore- nd and make up most of the wooded and low-lying pasture country. Old Red Sandstone which should separate these two systems is missing was probably never deposited in this area.* *(Geological Survey photograph (Crown copyright reserved); lettering added.)*

FIGURE 9 – *Snowdon from the east, with Llyn Llydaw in the foreground. The mountain has been eroded out of a syncline of Ordovician volcanic rocks with the highest beds of fossiliferous ashes occurring near the summit. Glacial moraines and drift cover the foreground and middle distance.*

(Geological Survey photograph (Crown copyright reserved).)

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FIGURE 10 – *A Wealden landscape: restoration of the shores of the Wealden lake, with the reptiles Iguanodon (foreground), Brontosaurus (emerging in the background) and a Pterodactyl gliding overhead. Among the plants shown are conifers, cycads, and ferns.*
(From a diorama in the Geological Museum. Geological Survey photograph (Crown copyright reserved).)

FIGURE 11 – *Reconstruction of a typical Coal Measure forest scene, from a diorama in the Geological Museum, London.*
(Geological Survey photograph (Crown copyright reserved).)

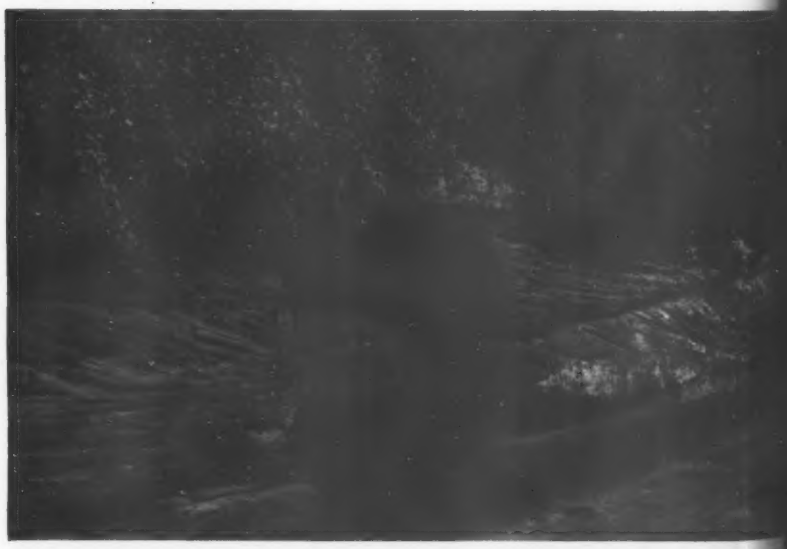

FIGURE 12 – *Road section showing dune-bedding in the Trias (New Red Sandstone) at Brimstree Hill, Salop.*
(Geological Survey photograph (Crown copyright reserved).)

were probably then, as now, dry land and formed the northern margin of a narrow isthmus or elongated peninsula which separated the main Welsh trough of deposition from a northern sea in which were laid down the peculiar calcareous Cambro-Ordovician rocks of the north-west Highlands with their strongly American affinities. In Cambrian times, the southern shore of this land barrier was perhaps in the region of Anglesey, trending approximately north-east, while open sea dotted with islands extended eastwards towards the Baltic. Pre-Cambrian rocks in Shropshire, the Malverns, the Lickey Hills, Charnwood, and probably those regions near Northampton, Bletchley, and the Norfolk coast, where deep bores have revealed pre-Cambrian rocks immediately beneath the Mesozoic, must all have been islands projecting out of the Cambrian sea. They form a broad east-west belt, but are probably the peaks of a complex system of low ridges trending more north-south or north-west–south-east.

FIGURE 13 – *Schematic geological map of Britain with the cover of Tertiary and Mesozoic rocks removed. The absence of Upper Palaeozoic rocks over much of the south-east area is no doubt due largely to post-Carboniferous uplift and erosion; but there are some areas where even Upper Carboniferous rocks were never deposited and snags of pre-Cambrian and Lower Palaeozoic rocks representing a rugged island belt extending eastwards across the Midlands are shown projecting through the Upper Palaeozoic. Shading as in figure* 1.

In the succeeding Ordovician period, the shoreline of the main Welsh trough moved away to the north-west, submerging the Lake District and the Southern Uplands of Scotland. We then have evidence of a roughly parallel shoreline to the south-east—the coast of a southern land-mass occupying eastern England and the Midlands, where the Ordovician was never deposited. There is no indication of sediments later than the Lower Ordovician in the north-west Highlands, and no further evidence of that northern sea; but the fossil faunas of the Southern Uplands region sometimes suggest American affinities in the later Ordovician. The Ordovician period is noteworthy for its volcanic activity, submarine volcanoes in North Wales and the Lake District ejecting great thicknesses of lava and volcanic ashes (figure 9).

In Silurian times, while the northern shoreline remained approximately unchanged across central Scotland, the sea spread again south-eastwards, submerging first the coastal zone of the eastern land-mass, and finally the whole of eastern England as in Cambrian times. Late Silurian sediments are shallow-water in character, with occasional indications of brackish deposition, bringing to a close the great Lower Palaeozoic marine phase.

During this phase, sediments in the deeper part of the trough had attained an aggregate thickness computed at about nine miles, so that as the floor of the trough continued to sink and fresh sediment poured in, the earlier deposits were buried to a very considerable depth, and must have been subjected to high temperatures. While no true metamorphism (recrystallization) occurred, the subsequent compression as the trough was squeezed beneath its heavy overburden in places converted the Cambrian shales to perfect slates (as for instance in the North Wales slate belt) and even the Ordovician volcanic ashes of Wales and the Lake District assumed a rude cleavage across their original bedding planes. The most spectacular deformation attributed to these Caledonian movements occurs among the pre-Cambrian and Cambrian rocks in north-west Scotland, and the pre-Cambrian of the Grampians, though deformation

of the latter may be of some pre-Cambrian age. In the former area, crystalline pre-Cambrian rocks have been carried forward for miles along almost horizontal fracture-planes or thrusts, to come to rest upon Cambrian sediments lying undisturbed and unaltered on the stationary pre-Cambrian block to the north-west (figure 6). In the Grampians, pre-Cambrian rocks have developed huge horizontally-lying folds before finally yielding to thrust displacement. Further south, the soft Lower Palaeozoic shales of the Southern Uplands have developed a steeply inclined concertina-folding; while in the Lake District and North Wales large-scale simple folds are sometimes associated with thrusting. Snowdon (figure 9) is the eroded remnant of a large, deceptively simple-looking basin or syncline of Ordovician volcanic rocks, lying between the Cambrian and pre-Cambrian rocks of the Menai region and the great Harlech Dome (Cambrian). The rugged scenery of the Lake District has been carved out of a great anticline of Ordovician slates and volcanic rocks.

A newly elevated land-surface, diversified by what must have been high mountain ranges over Wales, the Lake District, and Scotland, now occupied all Britain north of an almost east-west coastline passing through the Bristol Channel region. The Caledonian movements had welded Britain to a great northern continent, which may have extended so far as to include Scandinavia, Spitsbergen, and Greenland.

Between the main mountain ranges, huge outwash-fans of sediment (the Old Red Sandstone) accumulated in a semi-arid climate with torrential seasonal rains. True lake deposits are not much in evidence in the Lower or Upper Old Red Sandstone, but extensive waterlaid deposits of Middle Old Red Sandstone age are found in the Shetlands, Orkneys, and adjacent mainland, an area to which the name Lake Orcadie has been given. Altogether, but not all in one place, the succession of Old Red Sandstone sediments amounts to a thickness of 20,000 feet or more. Earth movement in the nature of readjustment continued well into Old Red Sandstone times; outpourings of lava characterize the Lower Old Red Sandstone of southern and central Scotland, and many of the northern granite intrusions are of this age. To the south lay the sea, in which were deposited the contemporaneous marine rocks of Devon and Cornwall, and, away to the east, the Ardennes and the Rhine provinces.

This land surface with its great pockets of Old Red Sandstone was by no means completely levelled by erosion before submergence allowed an irregular northward transgression of the sea, and England entered upon its second marine phase.

The Carboniferous is a vast system, representing a time interval of some 80 million years—half as long again as the whole of the Tertiary and perhaps two-thirds of the entire Mesozoic. Conditions of deposition and shorelines varied so greatly during this time that we cannot attempt to consider it as a single unit. Towards the end of Lower Carboniferous times, most of England was submerged; but a large part of Wales stood up as a sizable island perhaps extending to the Irish coast, and an archipelago of smaller islands stretched eastwards across the Midlands—an echo of those islands strung across the Midlands in the Lower Palaeozoic. Deltaic conditions existed in central Scotland at the mouths of great rivers draining the land further north, and irregularly-scattered islands lay offshore in the Southern Uplands, the Lake District and perhaps north-east Ireland. The overlying Millstone Grit is a complex deltaic deposit of grits and shales, interspersed rarely with marine shales marking repeated subsidence. This overspread most of the country and in turn gave place to the Coal Measure forest swamps (figure 11), spreading down from the north, alternating during periods of subsidence with sandstones, silts, and shales of freshwater, estuarine, and rarely marine origin. Finally, at the top of the Carboniferous strata, unproductive 'red measures' indicate the onset of arid conditions. The truly marine phase of the Carboniferous was of relatively short duration, but the peculiar deltaic and swamp conditions of the Middle and Upper Carboniferous accompanied long-continued subsidence, and their sediments accumulated to a great thickness. By the end of the Carboniferous period, subsidence and sedimentation together had probably swamped all but the peak areas of the Caledonian mountain system.

Now came the second great period of earth movement, the full force of which was felt more in north-west Europe than in Britain itself. The greatest effects here are seen in Devon and Cornwall, where slaty cleavage has been developed in Devonian shales; and the Bristol and South Wales coalfields show a more severe contortion than those of the north. Folding of the Coal Measures and underlying rocks was conditioned, particularly in the Midland area, by the submerged or semi-submerged ribs of hard pre-Cambrian and

Lower Palaeozoic rocks beneath. To this period also is to be attributed the trough-faulting of the midland valley of Scotland, which has let down and preserved from erosion the Old Red Sandstone and Carboniferous rocks of industrial Scotland.

Again Britain was firmly incorporated in a northern land-mass, now lapped to the east of the Pennines by the margin of a great desiccating inland sea, centred over Germany, in which was deposited the Magnesian Limestone with its associated beds of marl, rock-salt, and gypsum. This series of strata rests upon a remarkably level surface planing the East Pennine coalfields. Elsewhere the surface shows a somewhat greater relief. Semi-arid and desert conditions prevailed over the low-lying areas between the upstanding masses to the west and north-west, and the Palaeozoic platform to the east where the New Red Sandstone accumulated. Rock-salt, gypsum, and red marls betoken the drying-up of small inland seas, and current-bedding of the sandstones (figure 12) proclaims wind action as surely as the polished surfaces of pre-Cambrian that project through the New Red Sandstone marls at Charnwood Forest.

Submergence of this land is reflected in the transition to marine deposits of the Jurassic, whose approximate eastern shoreline has already been indicated (figure 5 (*b*)). The western coast is more difficult to locate, for to that side lie the eroded edges of the present-day outcrops at surface; but there is reason to suppose that Wales and western England were mainly dry land. Nor did the sea extend very far to the north, for in this direction the Jurassic deposits become deltaic in character, providing a curious parallel to the conditions that existed in the Lower Carboniferous period. Further north, a narrow inlet, at times perhaps an estuary, seems to have followed round what is now the west coast of Scotland, and traces of the sediments deposited there are preserved under the cap of Tertiary lava.

The continuity of the Mesozoic marine phase was very nearly broken at the end of the Jurassic; uplift led to a narrowing of the sea, and eventually to the appearance of a land-bridge across the Midlands, separating a marine area to the north-east from a freshwater lake to the south-east and south. Thus all but a portion of south-east Lincolnshire had become dry land or freshwater swamp (figure 10). The marine transgression of the Cretaceous, after breaking through this land-barrier, carried the sea as far north-west as Antrim and the Western Isles. Whether Wales and the Lake District were submerged even then is open to doubt; but the Palaeozoic land-mass of south-east England vanished beneath the Chalk seas and has never since reappeared at surface.

The ensuing uplift revealed by the slight pre-Tertiary unconformity was of short duration in south-east England, which was soon submerged again beneath the shallow waters of an eastern sea. This sea stretched away to the east and south-east to include in the same general area of deposition the Tertiary rocks of the Paris basin, Belgium, and Holland (the Anglo-Parisian basin). To the north-west, early Tertiary volcanic action built up a great basaltic plateau, two or three thousand feet high, of which the remnants are today found in Northern Ireland and the Western Isles of Scotland (figure 7).

The Caledonian earth movements were severely felt in Britain; the Permo-Carboniferous movements less intensely; and still less the mid-Tertiary or Alpine movements, whose effects are practically confined to south-east England. Locally, along the Hog's Back, near Guildford, and in the Isle of Wight and in Purbeck, dips rise to verticality, but over most of the area the regional dip rarely exceeds two or three degrees. The London and Hampshire basins and the Weald anticline are large-scale but very shallow structures.

Erosion of the Weald anticline was rapid, for marine sands of Lower Pliocene age rest directly upon Chalk at places on the North and South Downs and the Chilterns. The uplift that followed left the whole of Britain dry land, except for the eastern edges of Norfolk and Suffolk, which received the marine shell-banks or 'crags' of the Upper Pliocene.

By then the present topography and outcrops had been virtually determined, save for relatively minor effects of the Quaternary era. Moving valley-glaciers left their characteristic modifications on upland topography; and vast ice-sheets blanketed lowland areas of all but southern England with deposits of boulder-clay and drifts. Diversion of drainage occurred here and there, through blocking of pre-Pleistocene valleys with ice or drift; and changes in sea level, due to loading and unloading of the land surface with ice, resulted in drowned valleys, submerged forests, and raised beaches around our coasts. To us, the most important of all Quaternary events was the break-through of the sea at the English Channel.

NOTE: Figures 6–12 are reproduced from photographs supplied by the Geological Survey, by permission of the Director of the Geological Survey and the Controller of H.M. Stationery Office.

The Royal Society of Edinburgh

JAMES KENDALL

The title of Fellow of the Royal Society of Edinburgh has long been recognized as a high academic honour. Among the many distinguished scientists who have been Fellows of the Society may be mentioned Joseph Black, Thomas Hope, James Hutton, Thomas Graham, Clerk Maxwell, Crum Brown, and Lord Kelvin. Literary genius has been represented by Goethe and Sir Walter Scott (President from 1820 till 1832). Professor Kendall here recounts the history of the Society, unbroken from its foundation in 1783 up to the present day.

The Royal Society of Edinburgh, like its senior sister the Royal Society of London, did not spring suddenly into existence; it gradually evolved from a series of less formal associations originating in a period of civil stress. The Philosophical College instituted in London during the struggle between King Charles I and Parliament in 1645, and continuing its sessions at Oxford during the Protectorate, had its northern counterpart, a century later, in the Philosophical Society of Edinburgh.

This Society itself was an amalgamation of two more specialized bodies —a Medical Society, founded in 1731, and a Society for improving Arts and Sciences, six years younger. Alexander Monro *primus*, the anatomist, was the secretary of the former; the six volumes of *Medical Essays and Observations* communicated to the Society and published under his supervision assisted significantly in spreading the fame of the Edinburgh Medical School throughout Europe. Colin Maclaurin, the mathematician, was the moving spirit of the latter, but his exertions in the attempted defence of Edinburgh against the Jacobite army in 1745 led to his untimely death and the temporary suspension of all its activities. When tranquillity was restored the two conjoined societies, with David Hume and Alexander Monro *secundus* as secretaries, settled down once more to serious business; three volumes of *Essays and Observations, Physical and Literary*, published between 1754 and 1771, contain contributions on a wide range of subjects by leaders in almost every field of science, philosophy, and letters.

FIGURE 1 – *Sir William Wright Smith, Present President of the Society.*
(From a painting by Stanley Cursiter, R.S.A., F.R.S.E.)

In 1782, however, a new crisis arose. Lord Buchan's petition for a charter for the Society of Antiquaries of Scotland was opposed by the University, at the instigation of its principal, William Robertson, who preferred one comprehensive learned society; and this opposition, vain though it proved, was the immediate cause of the formation of the Royal Society of Edinburgh. Writing to a friend on 30th November, 1782, Andrew Dalziel, Professor of Greek, remarked:

> Lord Buchan is kicking up a sad dust about his Antiquarian Society. He has admitted such a number of ragamuffins that the respectable members are resigning very fast, and joining the University and Faculty of Advocates in an application for a Royal Charter for a new Society.

Robertson's scheme, as finally adopted at a meeting of the professors of the University, many of whom were members of the Philosophical Society, called indeed for 'the establishment of a New Society on a more extended plan, and after

FIGURE 2 – *John Robison, General Secretary* 1783–98.
(From a painting by Sir Henry Raeburn, F.R.S.E.)

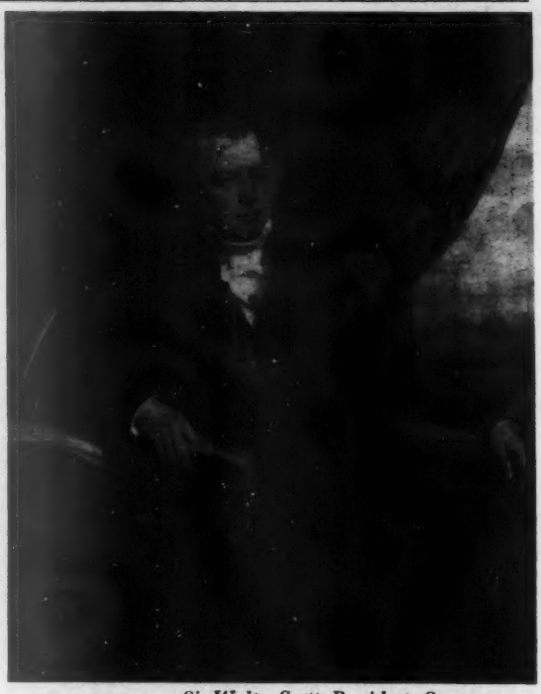

FIGURE 3 – *Sir Walter Scott, President* 1820–32.
(From a painting by J. Graham-Gilbert.)

the model of some of the foreign Academies, which have for their object the cultivation of every branch of science, erudition, and taste.' The patronage of the King was solicited, and a Charter of Incorporation was granted by King George III in March 1783.

The first meeting of the Royal Society of Edinburgh was held on 23rd June of the same year, in the University Library, with Principal Robertson in the chair. It was resolved that all members of the Philosophical Society should be assumed as Fellows of the Royal Society. The Duke of Buccleuch was elected president, and John Robison secretary. Buccleuch's appointment was essentially titular, although he did contribute to the first volume of the Society's *Transactions* an extensive record of the weather and the rainfall at his various country seats. Robison, on the other hand, the Professor of Natural Philosophy at the University of Edinburgh, was an 'Admirable Crichton' type of scientist, who had previously occupied the chair of chemistry at Glasgow, in succession to Joseph Black, and the chair of mathematics at the Naval College, Kronstadt. As a young man, he was in the same boat with Wolfe before the capture of Quebec, and recorded the doomed general's recital of Gray's *Elegy* during the journey up the St. Lawrence to the Heights of Abraham. His portrait by Raeburn, presented by his son Sir John Robison, a subsequent secretary, is probably the most valuable possession of the Society today.

The Fellows, as also the published *Transactions* of the Society, were originally divided into two classes—physical and literary—but it soon became obvious that the scientific side was to be predominant. Very few literary papers were submitted, and separate meetings of this class soon ceased to be held. Only one literary president of the Society was ever appointed, namely Sir Walter Scott, who held office from 1820 to 1832. His portrait, by Graham-Gilbert, also hangs in the Society's rooms. He was, for a long time, most conscientious in his attendance at all functions; Charles Darwin mentions in his *Autobiography* that he went to a meeting of the Society in 1827, when he was a medical student at Edinburgh, and saw Walter Scott in the chair.

The scientific publications of the Society immediately took their place in the front rank. In the very first volume of the *Transactions*, James Hutton began a geological conflagration which blazed

fiercely throughout Europe for many years afterwards by a communication on his Theory of the Earth, over which the Neptunists and the Vulcanists fought with much fury. His main principles were ultimately generally accepted, and he is regarded as the father of physical geology. Sir James Hall, the second president of the Society, tested and confirmed Hutton's conclusions by direct experiment, and may be called the father of experimental geology. In chemistry, Joseph Black sang only his swan-song in a routine analysis of the waters of some hot springs in Iceland, but his pupil and colleague Thomas Hope added a new element to knowledge in his 'Account of a Mineral from Strontian, and of a peculiar Species of Earth which it contains.' In Vol. XII, Thomas Graham published his celebrated 'Memoir on the Law of Diffusion of Gases.' Other branches of science were equally well represented, but it is a pity that Adam Smith, a Charter Fellow, did not add to the *Wealth of Nations* by any contribution to the Society's publications.

FIGURE 4 – *Lord Kelvin, President* 1873–78, 1886–90, 1895–1907.
(*From the Herkomer portrait in Glasgow University.*)

From its foundation the Society exercised the right of electing a limited number of foreign Honorary Fellows; Benjamin Franklin was among the first to be so distinguished. Most of the leaders in scientific progress in all parts of the world during the past 150 years have found a place on the list, but the only name which calls for particular mention here is that of J. Wolfgang Goethe. Goethe was very appropriately elected during the presidency of Sir Walter Scott, and it is interesting to note that he received the honour for his distinction in science as well as in literature. Goethe himself was of the opinion that his poetry would be forgotten but that his work on light and colour would live. Time has proved the opposite.

As science expanded during the nineteenth century, it became necessary to divide the publications of the Society into *Proceedings* and *Transactions*, and recently the *Proceedings* themselves have been subdivided into two sections—Physical and Biological. The total mass of work published in the sixty-two volumes of *Proceedings* and sixty-one volumes of *Transactions* is too immense to admit of any analysis here; a few items of exceptional character do, nevertheless, deserve brief comment.

In 1846, for instance, Clerk Maxwell, then a boy of fifteen at the Edinburgh Academy, wrote his first paper for the Society on the 'Properties of certain Oval Curves' — the manuscript is still preserved. His teacher, Forbes, however, had to read both this communication and another submitted a year later on Rolling Curves or Roulettes, for it was not considered proper for a boy in a round jacket to address the Society! Could it have been foreseen that this boy was destined to become the greatest mathematical physicist of the century, a different decision might have been given.

In 1873, a youth not many years older than Clerk Maxwell *was* permitted to read a paper, a dreary article 'On the Thermal Influence of Forests.' Perhaps he was favoured by the fact that his father was a prominent Fellow of the Society—eleven years later, indeed, its president. A typical sentence from this communication runs as follows:

> A wood, then, may be regarded either as a *superficies* or as a *solid*; that is, either as a part of the earth's surface slightly elevated above the rest, or as a diffused and heterogeneous body displacing a certain portion of free and mobile atmosphere.

This is not nearly as exciting as *Treasure Island* or *Kidnapped*, but its author was no other than Robert Louis Stevenson!

The latter half of last century was a golden age for the Society under the able guidance of the famous firm 'T and T'—Sir William Thomson (Lord Kelvin) and Peter Guthrie Tait. Kelvin

was president for three terms, twenty-one years in all; Tait was Secretary to Ordinary Meetings and General Secretary for a total period of thirty-seven years. Many of Kelvin's research papers and nearly all of Tait's are included in the Society's publications. Crum Brown in chemistry and Chrystal in mathematics were other giants of this era.

Towards the close of his final term of office, Kelvin saw the Society safely through a critical domestic upheaval. For more than eighty years it had occupied a suite of rooms in the Royal Institution, the monumental building facing Princes Street at the foot of the Mound. In 1906, however, the Secretary for Scotland introduced into the House of Commons a bill providing that the Royal Institution should become a National Gallery and be applied to the promotion of the Fine Arts. Faced with compulsory removal, an influential deputation of Fellows, headed by Kelvin, urged upon the Government the claims of the Society for State support in obtaining adequate alternative accommodation for its meetings, its valuable library, pictures, and manuscripts, and the transaction of its general business. A clause was inserted into the bill by which the requisite funds were assured, and in 1909 the new home of the Society in George Street was opened by Sir William Turner, Kelvin's successor in the presidential chair.

The premises provided appeared commodious then, but they are congested now. Inordinate expansion of the membership of the Society has been checked by limitation of new Fellows to twenty-five annually—a move which will certainly enhance the high prestige that has always attached to the letters F.R.S.E.—nevertheless the attendance at most of the regular monthly meetings overcrowds the reception rooms, and even standing space in the lecture theatre is frequently at a premium. More serious still is the library situation; the Society participates in more than 600 exchanges over the whole world, and its collection of scientific periodical literature and works of reference is one of the most complete in the British Empire; but the saturation point for stacking new volumes is already exceeded, and the official Curator will be faced with an insoluble problem when war-time arrears are re-established. Facilities for the exhibition of the Society's manuscripts are also most urgently needed.

The Society has in its award a number of prizes. The Keith and Makdougall-Brisbane Prizes are both given biennially, in the physical and biological sciences alternately, for the best communication to the Society's publications during the period immediately preceding. The Neill Prize is also awarded biennially for a paper of distinguished merit, on some branch of natural history, by a Scottish naturalist. The Gunning Victoria Jubilee Prize is awarded quadrennially in recognition of original work in physics, chemistry, or pure or applied mathematics, and is open to men of science resident in or connected with Scotland. The James Scott Prize is offered triennially for a lecture or essay on the fundamental concepts of natural philosophy, and the Bruce Prize biennially for some notable contribution to natural sciences, 'the outcome of a personal visit to polar regions on the part of the recipient.' In addition, the Bruce-Preller Lecture Fund affords biennially an honorarium for an address by an outstanding man of science in geology or electrical or physical science, and the David Anderson-Berry Fund a triennial medal and prize for an essay on X-rays and their therapeutical effect. Finally, under a recent bequest by the late Mr Robert Cormack, the Society has been directed to administer the residue of his estate, approximately £54,000, for the purpose of promoting astronomical knowledge and research in Scotland.

To end on a less monotonous note, mention may be made of a Dining Club of the Society, founded in 1820. Its functions are explained by Sir Walter Scott as follows:

> It is a very good institution; we pay two guineas only for six dinners in the year, present or absent. Dine at five, or rather half-past five, at the Royal Hotel, where we have an excellent dinner till half-past seven, then coffee, and we go to the Society. This has great influence in keeping up the attendance, it being found that this preface of a good dinner, to be paid for whether you partake or not, brings out many a philosopher who might not otherwise have attended.

When the length of the repast, at which 'mulled wine and punch were manufactured and consumed according to the latest philosophical discoveries,' is borne in mind, it is not surprising to learn that Scott, on 4th December, 1826, 'listened without understanding a single word, to two scientific papers; one about the tail of a comet, and the other about a chucky-stane.' To avoid such lapses nowadays, the dinners are held *after* the ordinary scientific sessions. During the war, of course, all convivial activities were suspended, but the 599th meeting of the Club—a Victory celebration—was held with moderated austerity on 3rd December, 1945.

Mineral deficiencies in plants

T. WALLACE

Few scientific discoveries have had greater economic and social effects than the recognition of the importance of minerals in plant nutrition. From it has arisen one of the most important branches of chemical industry, the production of fertilizers. Professor Wallace here discusses problems relating to the diagnosis, cause, and cure of mineral deficiencies in the field, proper understanding of which is necessary to the most effective use of fertilizers.

Little more than a century has elapsed since Liebig, in 1840, first advanced his theory of the mineral nutrition of plants. Subsequent practical experience and scientific investigations have fully confirmed the importance of minerals in crop production, and various aspects of mineral nutrition of plants have been closely investigated. Particular attention has been paid to the identification of the elements essential for the growth of plants, and to the effect on various growth processes of the omission of one or more of these elements from the nutrient medium. Since crop plants satisfy a considerable part of the mineral requirements of cattle, an important aspect of recent research has been the investigation of the relationship between the mineral deficiencies of plants and the health of stock feeding on them [1].

Experimental methods used in problems of plant nutrition have been of three main kinds. There have been extensive trials of crops under field conditions, carefully controlled experiments using pot or water culture methods, and, finally, elaborate experiments in the laboratory using highly refined methods of chemistry and plant physiology. The elements concerned with the growth of plants fall into three groups: the *essential major elements*—nitrogen, phosphorus, calcium, magnesium, potassium, and sulphur—which are required in relatively large amounts; the *essential trace elements*—iron, manganese, boron, copper, zinc, and molybdenum—which are equally indispensable but are required in only very small quantities; and four elements—sodium, chlorine, silicon, and possibly aluminium—which, although perhaps not absolutely essential, are definitely beneficial for certain plants.

Deficiency of any of these elements may be of an absolute or a relative kind. It may arise directly from an acute shortage of the particular element in the soil, or from a relative shortage induced or accentuated by an excess of some other element. Thus a deficiency of potassium may arise from excess of nitrogen or phosphorus. Deficiencies of the trace elements iron and manganese are largely determined by the *p*H of the nutrient medium, these two elements being less readily utilized by plants at high *p*H values; boron deficiency too is often induced by liming. On the other hand, the molybdenum content of the herbage of 'teart', i.e. scouring, pastures assumes proportions toxic to animals when the *p*H of the soil is high. Finally, it must be emphasized that mineral deficiencies are related to the general plant environment: in particular to conditions of the atmosphere and soil, such as light intensity, temperature, and moisture content.

From the point of view of practical agriculture, important aspects of mineral deficiency investigations are (*a*) those relating to the effects on the various crop plants of specific deficiencies, (*b*) methods of detecting the exact nature of any deficiency, and (*c*) the practical means of correction under field conditions. In many crops, symptoms of specific deficiencies are so characteristic that they can be recognized by visual inspection, and this has made possible the method of visual diagnosis which has proved of great practical value. Where the visual method cannot be applied or requires confirmation, other quick tests, including chemical, spraying, and injection techniques are used [2].

Nitrogen deficiency leads to a general stunting and sparsity of growth. The leaves of affected plants are generally pale and tend to assume bright yellow, red, or purple tints. Blossoming, seed formation, and fruiting are much reduced. The effects of *phosphorus* deficiency are in many respects similar to those of nitrogen deficiency, but the leaf tints are often dull purple or the foliage may merely lack lustre and appear dull green. Leaf margins may look scorched, as in potatoes, or spots may develop over the whole leaf, as in

FIG
gins

FIGURE 1 – Rape Plant. *Calcium deficiency. Leaf margins and mesophyll wilt and collapse.*

FIGURE 2 – Cauliflower Plant. *Manganese toxicity developed under conditions of calcium deficiency. Manganese toxicity shows as curling and spotting of leaf margins, and calcium deficiency as necrosis of the mesophyll. These conditions may develop together in plants on strongly acid soils.*

clovers and black currants. Symptoms of *calcium* deficiency first appear near growing points and in roots. Leaves become distorted, rudimentary, rolled, and scorched; roots are often stumpy; tuber formation, as in potatoes, is greatly restricted. Soil acidity, which accompanies calcium deficiency in the field, may induce manganese toxicity effects, such as chlorosis and leaf rolling, as secondary symptoms (figure 2). *Magnesium* deficiency particularly affects the foliage. Chlorosis is common but brilliant tints are also frequent; leaves are shed prematurely, often without previous withering. Despite the severity of leaf symptoms and extensive defoliation, the effect on crop yields may not be serious. The symptoms of *potassium* deficiency vary with its severity. Slight deficiency restricts the growth of shoots whilst severe deficiency may cause them to 'die back.' Growth generally appears squat, because of short internodes, and flowering stems may fail to develop. Leaf symptoms are generally characteristic and usually include marginal scorching, tip burn, or spotting; and intervenal chlorosis may occur. The laminae may be rolled forward parallel with the midrib or may be gently curved back. Grain and fruits are generally small and of poor quality. *Sodium* deficiency is seen only in sodium-loving crops such as sugar beet and mangolds. Leaves are dark green, lack lustre, and wilt rapidly in drought. *Sulphur* deficiency has not been reported in Great Britain. When it is deliberately induced in plants, the symptoms somewhat resemble those of nitrogen deficiency.

Lack of *iron* is characterized by severe chlorosis of the tip leaves of young growths; this is generally followed by 'die back' of the shoots. The leaves may be entirely bleached, or chlorosis may take the form of mottling, as in *Brassicae*, or intervenal stripes, as in cereals. In *manganese* deficiency too, leaf symptoms are generally notable. Chlorosis, similar to that due to lack of iron, is common, but many plants show other characteristic symptoms. In oats, for example, the condition known as 'grey speck' appears. Chlorosis generally follows a well-defined pattern but, unlike that associated with iron deficiency, is not most severe on the leaves at the tips of shoots. Peas, and occasionally various types of beans, develop circular brown lesions on the flat surfaces of the cotyledons in the seeds (Marsh Spot) (figure 12).

The symptoms of *boron* deficiency [3] are generally so characteristic that for many plants they have been assigned definite descriptive names, such as 'Crown Rot' of sugar-beet and mangolds,

FIGURE 3 – Barley Plants. *Potassium deficiency. Leaves are semi-chlorotic and show irregular white lesions.*

FIGURE 4 – Mangold Plant. *Potassium deficiency. Leaves show marginal and intervenal scorching. The older leaves are affected first, wither prematurely, and fall to the ground.*

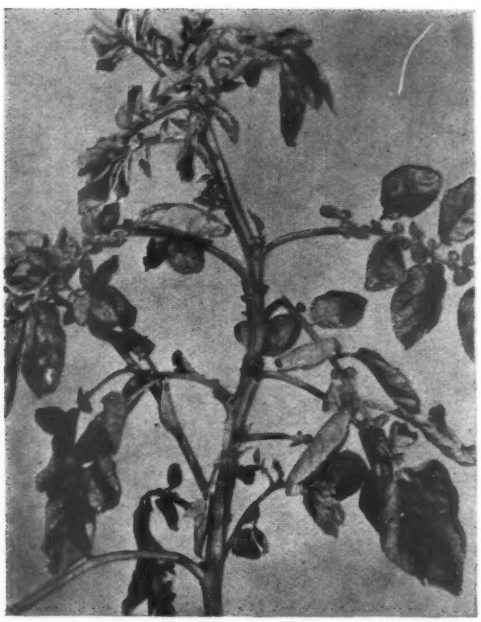

FIGURE 5 – Potato Shoot. *Calcium deficiency. Shoots are much branched and young leaves are very small with margins folded towards their upper surfaces.*

FIGURE 6 – Apple Shoots. *Iron deficiency. The tip leaves develop chlorosis and later some marginal scorching. Severely affected shoots eventually die back.*

FIGURE 7 – Sweet Cherry Leaves. *Manganese deficiency. Leaf margins become chlorotic and the chlorosis spreads intervenally as a V-shaped pattern towards the midrib. The whole lamina may eventually be affected.*

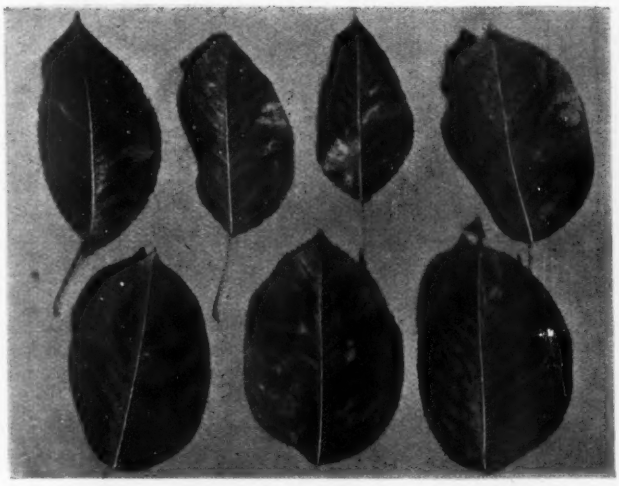

FIGURE 8 – Pear Leaves. *Magnesium deficiency. Intervenal areas around the midrib become necrotic.*

FIGURE 9 – Cauliflower Plant. *Magnesium deficiency. Older leaves show chlorotic 'marbling' and may also develop red and purple tinting.*

FIGURE 10 – Tomato Foliage and Fruits. *Magnesium deficiency. The foliage, beginning with older leaves and progressing to the younger, becomes chlorotic and later brown necrotic areas are developed intervenally.*

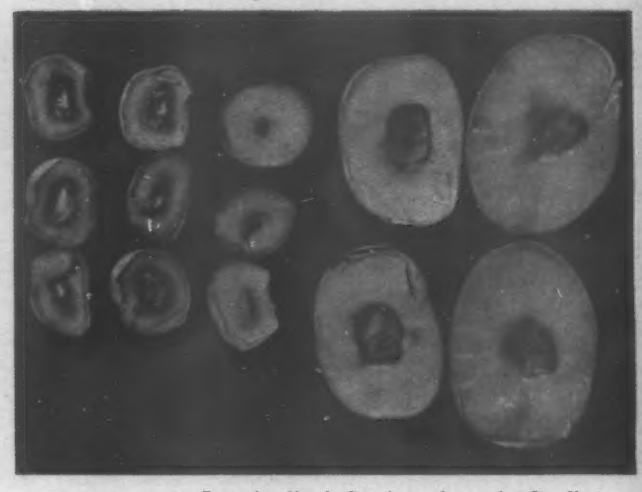

FIGURE 11 – Longitudinal Section through Cauliflower Head. *Boron deficiency. The curd is brown and the pith of the main stem shows brown lesions.*

FIGURE 12 – Pea and Broad Bean Seeds. *Manganese deficiency. The cotyledons show brown lesions in their centres. (In peas the condition is termed 'Marsh Spot.')*

'Canker' of table beet, 'Brown Heart' or 'Raan' of swedes and turnips, 'Hollow Stem' or 'Browning' of cauliflowers, and many others. Growing points are generally so seriously affected that they die; the pith and epidermis of stems are damaged, giving rise to characteristic hollow and roughened stalks; leaves often show marginal scorching, mottling, and pigment formation, besides being cracked and wrinkled; fruits become dwarfed and malformed, and often develop internal necrosis.

Although deficiencies of *zinc*, *copper*, and *molybdenum* are important in many crops abroad, they have not been recorded in any field crop in Great Britain. Zinc deficiency is the cause of serious diseases in many fruit trees such as Citrus, apples, pecans, vines, and stone fruits [4]. 'Bronzing' of tung and 'White Tip' of maize result from lack of zinc, which is also responsible for poor yields of cereals from certain Australian soils. Deficiency of copper [5] causes serious pathological conditions in fruit trees, notably *Exanthema* of Citrus, etc. In Holland and Denmark it affects cereals, and is known as 'Reclamation Disease.' Australian cereal crops also are known to be affected. Molybdenum deficiency has been noted only in pasture plants and peas on certain ironstone soils in South Australia and Tasmania [6] [7]. Piper states that when the condition is deliberately induced in oats grown in water culture the following symptoms appear: necrosis occurs in upper leaves; the collapsed tissue dries and assumes a reddish brown colour; grain often fails to form.

This account of the visible symptoms of various types of mineral deficiency has been given in sufficient detail to illustrate the variety of the effects observed, permitting of differential diagnosis, and to emphasize the fact that their distribution and effects are such as to result in considerable losses in many crops.

Having described the effects of the various deficiencies, it is of interest to consider their distribution in relation to soils, and the methods of restoring the proper mineral balance when any particular deficiency occurs.

Deficiency of nitrogen may occur on any class of soil, and its occurrence is greatly influenced by the way in which the soil is managed and cropped. Thus supplies of soil nitrogen tend to increase under grass or leguminous crops and are decreased by arable cropping. A temporary deficiency may be induced if organic matter is ploughed-in in which the nitrogen–carbohydrate ratio is low. Provided other conditions are favourable for growth, the deficiency is easily remedied by the

application of nitrogenous fertilizers. The response is generally quick and spectacular, since nitrogen is very mobile in most soils, and the effects are so well known that details are unnecessary.

In Great Britain, phosphorus deficiency is most prevalent in the north and west, districts of high rainfall. Soils differ considerably in their natural supplies of phosphorus, and many clay soils—for example those of the Lower Lias—are particularly deficient. Strongly acid soils, ironstone soils, and soils derived from the chalk formations and Fen peats, are also generally lacking in phosphorus. A wide range of materials is available for supplying this element. If the deficiency is acute, it is generally best to use a soluble fertilizer, such as superphosphate, and, to be most effective, the dressing must be applied at an early stage in the growth cycle. Certain soils, notably ferruginous, strongly acid, calcareous, and clay soils, present special difficulties owing to their capacity for rendering phosphates insoluble and thus unavailable to the plants. Various devices have been suggested for overcoming this problem. One is the use of granular fertilizers, which present a relatively small surface to the soil: alternatively the fertilizer may be drilled with the seed so that close contact is ensured. A third method, devised for plants such as fruit trees, whose roots are deep, is to force the fertilizer into the soil with special lances.

Calcium deficiency is confined to acid soils, and is also most prevalent in districts of high rainfall owing to the ease with which calcium is leached from the soil. The occurrence of calcium deficiency is often associated with a low calcium content of the parent rocks from which the soils are derived. In the field it is difficult to distinguish the symptoms of this deficiency from those due to other effects resulting from the accompanying acidity of the soil. Although neutral calcium salts may be helpful in relieving a condition of calcium deficiency, they are no substitute for lime, which is the usual practical remedy, because of its property of neutralizing the accompanying acidity. With root crops, such as sugar-beet and mangolds, it is usually advisable on strongly acid soils to plough in some of the lime as well as to apply a top dressing, since otherwise the tendency is for the roots not to penetrate into the subsoil but to become fangy or to turn horizontally at a shallow depth.

Magnesium deficiency is most likely to occur on acid soils also lacking in calcium. It may also be induced by excess of potash and is accentuated by low nitrogen status. Control is obtained by dressings of magnesian limestone or magnesium sulphate. The former is preferable on acid soils, as it neutralizes soil acidity, but it frequently cannot be used on soils of high pH as, by further increasing the pH, deficiencies of iron or manganese may be induced. When magnesium deficiency results from excessive applications of potash, it may be necessary to discontinue the use of the latter, even for crops such as tomatoes, until the unfavourable magnesium balance is restored. With certain crops, such as glasshouse tomatoes and fruit trees, soil dressings of magnesium materials have proved very slow in action, and for the former crop much quicker results have been obtained by spraying the foliage with magnesium sulphate (2 per cent. magnesium sulphate, as the heptahydrate, plus spreader) [8].

Potassium deficiency occurs most frequently on light soils, but it may occur on soils of any texture when potash-loving crops are grown. In Great Britain, the deficiency is most prevalent in the area approximating to the great Chalk Belt which stretches from Dorset to Yorkshire. The condition is readily brought about by taking frequent hay crops, and is of common occurrence in freshly ploughed old grassland. It is best controlled by dressings of potassium fertilizers such as the sulphate, chloride, and nitrate, or kainit. A variety of waste materials containing soluble forms of potash may also be used; dung is a good source. Like phosphorus, potassium is fixed to a greater or lesser extent in all soils, and its action may therefore be comparatively slow. This is particularly so with fruit crops, where two or three seasons of treatment may be required to remedy the deficiency.

Low concentrations of sodium, and also of chlorine, are found most frequently in Great Britain on sandy soils remote from the sea. The most suitable method of correcting both deficiencies is by application of agricultural salt.

As already mentioned, sulphur deficiency is unknown in Great Britain, possibly because of the variety of materials containing it which are normally added to the soil. When it does occur, the remedy is treatment with any of the usual sulphate-containing fertilizers. Elementary sulphur can also be used, as this is readily converted into sulphate by micro-organisms in the soil.

A high pH of the soil, and possibly also a high phosphorus content, are probably the most important factors in inducing iron deficiency. The effect of a high pH is to render iron unavailable to

the plant, and it is generally impracticable to remedy the deficiency by adding iron salts to the soil. One method of treatment is to spray the foliage with a dilute solution (approximately 0·5 per cent.) of ferrous sulphate. In the case of trees, ferrous sulphate, ferric citrate, or ferric tartrate may be injected into the trunks and branches. The presence of actively decomposing organic matter or a grass cover tends to increase the availability of iron, and appreciable control can therefore sometimes be effected by incorporating dung into the soil or by growing a grass cover over the soil when trees are affected. The deficiency cannot usually be controlled satisfactorily in ground crops, but a method has recently been described for tomatoes, consisting of a peat mulch which is 'watered' with a solution of ferrous sulphate. The methods of treating iron deficiency cannot be said to be satisfactory, and it is the most difficult deficiency to treat in the field.

Manganese deficiency in England is associated with well-defined soil conditions. The most extensive areas occur in the Fens, Romney and Walland Marshes in Kent, and parts of Yorkshire. The special soil conditions usually present are a high *p*H (above 6·5), generally due to a high lime content, high content of organic matter, and imperfect drainage. During the war the trouble was especially marked on susceptible soil types when first crops were grown after breaking up old swards. The problems of controlling the deficiency are similar to those of iron, but the practical results of treatment are more satisfactory. Applications of manganese sulphate to the soil may be effective, but on some soils the results are disappointing. Soil treatment is ineffective for fruit trees, but control by spraying is practised with great success both on agricultural crops and with fruit trees. Effects due to overliming have been successfully overcome by application of sulphur, at the rate of about 1 ton per acre, but the treatment is too expensive. Sulphur thus applied lowers the *p*H of the soil. Good quality dung is effective in the season of application; basic slag may produce some benefits but has the disadvantage of further raising the *p*H of the soil.

Boron deficiency is probably determined mainly by the natural supplies of the element in the soil. It is most prevalent on light sandy soils and on those derived from chalk formations. It is often induced on sandy soils by liming. It is readily controlled by applications of borax or boric acid to the soil. In fruit trees it may also be controlled by stem injections or spraying with borax solution.

As zinc and copper deficiencies have not been recorded in Great Britain the corresponding soil conditions have not been determined here. The soil factors governing their occurrence are not understood, but low availability of zinc is thought to be related to the activities of the soil organisms and is induced by high concentrations of phosphorus. Copper deficiency is most prevalent on peaty soils but occurs also on sandy soils. Both deficiencies can be made good by application of the respective sulphates to the soil, or by foliage sprays or stem injections similar to those used for manganese.

The only recorded instances of molybdenum deficiency are in pasture plants and peas on ironstone soils in Australia and Tasmania. In 'teart' pastures, when molybdenum is present in toxic amounts in the herbage, the availability is increased if the *p*H rises. Deficiency has been controlled by application of ammonium or sodium molybdates, roasted molybdenite, or wood ashes. The available evidence suggests that less than 1 lb. of sodium molybdate per acre may be sufficient to prevent deficiency.

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Paludrine—a new antimalarial drug

FRANK L. ROSE

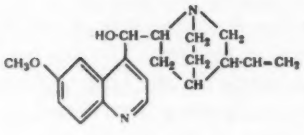
The capture of the East Indian quinine plantations by the Japanese, at a time when it was necessary to maintain large armies in some of the world's worst malarial regions, threatened to be a most serious blow to the Allied Nations. Fortunately the danger was overcome by manufacturing the synthetic drug, mepacrine, on a large scale. Although mepacrine proved very satisfactory, an intensive search was made in Great Britain for new and better anti-malarials and this work recently resulted in the discovery and development of paludrine.

Malaria is one of the major scourges of mankind. Even at the present time it attacks several hundred millions of people annually, and it is estimated that each year some three million die from the disease. It is impossible to compute how many more have their vitality so impaired that they fall an easy prey to other fatal diseases. In the past, malaria has wiped out entire populations, prevented colonization, and checked invading armies. Indeed, it is not an overstatement to claim for malaria a determining role in the history of the world. Nor does malaria occur only in the tropics. In former days it was rampant in Britain, when it was referred to as the ague, the malady from which Oliver Cromwell is said to have died. Even now it prevails in temperate zones as the tertian form, and the main tropical form (malignant subtertian) is to be found in the southern United States of America during certain seasons of the year. It is common knowledge that the disease is conveyed from man to man by an insect vector, the anopheles mosquito, but it is less well known that the causative parasites undergo a complicated life-cycle, some phases of which have not yet been fully elucidated. This article is concerned mainly with the chemistry of antimalarial drugs, but without a short account of some features of this life-cycle, it is not possible to indicate the full significance of the discoveries here described.

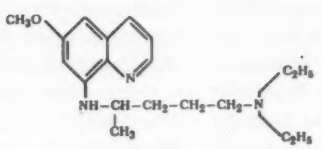
The word life-cycle denies a beginning for the existence of the malaria parasite, but it is convenient to break into the circle at the *sporozoite* phase, the form in which the parasites are concentrated mainly in the salivary gland of the mosquito. From here they pass to man when the insect bites. Then for a few days they disappear. Subsequent events prove that they are still alive and undergoing modifications, probably in the tissues of the body, but just what happens no one really knows, and to cover this ignorance it has been suggested that the parasites should be referred to at this stage as *cryptozoites*. The first time the parasites become visible in the human body is when they appear in the ring form either in, or attached to the surface of, the red blood-cells. After further development and upon the division of the nuclear chromatin material, the so-called *schizont* stage is reached, which then breaks up into numerous small bodies called *merozoites*. At the same time the host red blood-cell bursts, liberating these new forms into the blood-stream, where they seek other red cells and begin their multiplication yet again. The onset of fever coincides with this periodic rupture of the red cells, and the time-interval between rigors is a characteristic of the species of parasite causing the particular attack of the disease. After a few such cycles (*schizogony*), some of the parasites deviate from this course and differentiate while still in the red cells into male and female parasites known as *gametocytes*. These in time become free by destroying their host cells. They do not, however, divide again in man, but in course of time may be taken up by a mosquito partaking of a 'blood meal' from the human carrier. There is no need to detail subsequent events. Suffice to say that after further changes, in which sexual union is involved, the life history of the parasite turns full circle with the appearance once again of the sporozoites in the salivary glands of the insect.

When the investigations here described began, only three drugs were of importance in controlling human malaria. They were the naturally occurring quinine (and its near relations), and the synthetic substances mepacrine and pamaquin. Not one of these could be considered the perfect antimalarial. All produced toxic symptoms, and mepacrine in particular was a coloured substance which imparted a yellow stain to the skin. Quinine and mepacrine were restricted in their activity to the blood-forms of the parasite. In other words, they

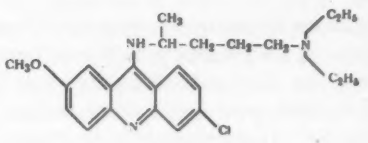
did not function until some time after the disease had entered the body, and then failed to produce radical cures. Pamaquin had a marked action against the gametocytes, preventing reinfection of the mosquito, and was also said by some workers to reduce relapse rates, but was so dangerously toxic that it could be used only under strict medical supervision. Finally, all these drugs were difficult to produce, and for this reason their use could not be extensive, for example, amongst native populations.



Quinine



Pamaquin



Mepacrine

The objective for further research was clearly then to produce a colourless, non-toxic drug, preferably of simple structure, which would be effective not only against the blood-forms, but against the earlier phases of the parasite, so that by acting as a true causal prophylactic it would eliminate the disease at the earliest possible stage.

Chemotherapy demands that, where possible, disease shall be studied first in small experimental animals, the smaller the better. There are several reasons for this. Firstly, direct experimentation with new drugs in human beings is undesirable, unless there is no alternative. Secondly, it is customary to administer drugs in dosages of so many grams per kilogram of body weight, and since many substances are extremely complex and their preparation even in the smallest amounts (1 gm. or less) is often a tedious business, the choice of small animals for experimental purposes allows the study of the action of the drug in the maximum number of 'cases.' Fortunately, many of the diseases to which man is subject, particularly some of the bacterial infections, can be reproduced in animals such as the mouse; and there exists a good chance that drugs discovered to be effective in this animal may subsequently prove active in the corresponding condition in man.

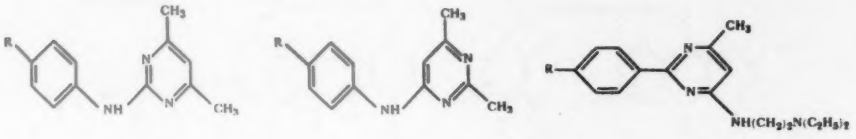
Malaria is less amenable to this kind of procedure. No small laboratory mammal is known which will 'take' human malarias. Forms of malaria are met with in the monkey tribe, but these animals cannot be considered small in the present sense, and in any event are probably the least tractable of experimental species. Some birds, however, can be infected by parasites related to those of human malaria. The parasite is transmissible through a mosquito, but is of a species different from that involved in human malaria. The parasite 'goes to earth' for a period of time after injection into the host, and then finally appears in the red cells of the blood. Suitable bird hosts are the young chick, duckling, Java sparrow, and canary. Each has its own peculiar susceptibilities to the several virulent parasite strains, called by names such as *Plasmodium* (or *P.*) *gallinaceum*, *P. lophurae* and *P. relictum*. A great deal of thought has to be given to the choice of the most suitable bird host and the most suitable parasite for laboratory investigations, bearing in mind that a wrong selection might mean the neglect of a drug valuable in human malaria, just because it was inactive, or almost inactive, in the particular experimental infection used. The counsel of perfection would be to run as many different strains in as many different hosts as is possible, thus minimizing the chances of such a happening, but in wartime Britain, when this decision had to be made, such a course was impracticable.

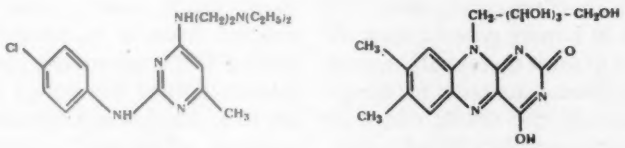
Space does not permit an account of the arguments adduced in support of the ultimate choice (a detailed account appeared in the December 1945 issue of the *Annals of Tropical Medicine and Parasitology*), but subsequent events have shown how wise was the selection of the young chick infected with *P. gallinaceum* in the initial tests for sorting out the compounds made by the chemists. Other hosts, infected with other strains of parasites, were not discarded, but used as 'second strings' to distinguish between drugs thought to act in different ways. An intensive study was made of that part of the life-cycle of the parasite which takes place in the chick, and it was tentatively suggested that in this species the sporozoite phase gives way to a *primary tissue phase* (or *exo-erythrocytic phase*), and this to the blood-forms. These in turn

revert to a tissue phase which may be closely related to the primary tissue forms. This secondary phase might itself lead to more blood or *erythrocytic* forms, and so the cycle in the host would be maintained. It was obvious that wide differences might be expected between the detailed life histories of the parasite in the chick and of the different species of parasite in man, but, taking into account all the available evidence, it was considered that the existence and persistence of a secondary tissue phase in man, such as was postulated for the chick, might account for the relapses which are met with in human malaria. With the chick test it was hoped, then, that it might be possible to distinguish between drugs which would act as true causal prophylactics, or as suppressants, or which would control the relapse rate.

When a new series of drugs is being investigated, it frequently happens that the first preparations exhibit but the merest trace of activity. Unless the biological test is highly sensitive, this trace-effect could easily be missed, and a chemical type that might ultimately have given drugs of great value would be passed by. One particular feature of the test developed in the present research was extreme sensitivity; and in addition it provided results, statistically sound, that distinguished between drugs of nearly equal activity. This told the chemists whether their chemical variations in a drug molecule were taking them nearer to, or farther away from, their goal.

The chemical aspect of the research has now to be considered. The initial step was to select a fresh molecular type for study. This was done deliberately, since it had become apparent that the extensive researches previously carried out all over the world on the basis of the three drugs mentioned above were not likely to provide a solution. For a number of reasons the choice fell upon the pyrimidine nucleus. Firstly, the chemistry of this ring system had become familiar in the course of work on sulphapyrimidine derivatives, and it had moreover just been learned that these latter compounds were effective to some extent in controlling malaria. Secondly, it was a structure that lent itself to the easy introduction of those chemical groupings tentatively considered to be of anti-



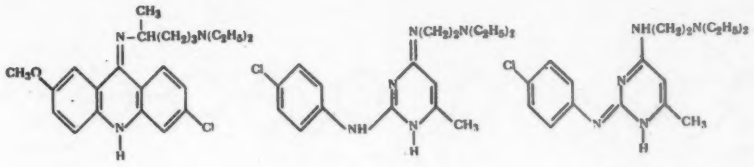


malarial significance; and thirdly, it was one of the 'vital' molecules occurring in many systems of physiological importance, such as the nucleic acids and numerous enzymes.

As to suitable ways of elaborating the pyrimidine ring to produce antimalarial drugs, consideration of the quinine and pamaquin molecules showed that these structures could be regarded as benzene derivatives containing methoxyl and associated with a ring nitrogen atom and a 'basic side chain.' The presence of chlorine in mepacrine suggested that this substituent might also promote antimalarial activity. The first preparations were very simple structures such as (I) and (II). These proved inactive. Dialkylaminoalkylamino side chains were then introduced into the molecules and (III) and 2666 were prepared. Of these, 2666 showed moderate activity as a suppressant against the blood-forms of the parasite in the chick. A preliminary clinical trial proved unsuccessful, but the first and greatest obstacle, that of discovering a lead, had been surmounted, and from then on the search for more active structures was intensified. The chemist always prefers to pursue his researches according to some plan, rather than to indulge in purely empirical variation of the

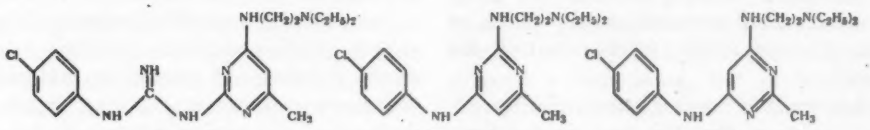
prototype molecule; and one of the most satisfactory methods in chemotherapy is to devise a hypothesis relating structure to biological effect, and then by suitable synthesis to seek to prove or disprove it. In the present instance several schemes were considered. One of these sought to explain the activity of 2666 on the basis of an apparent structural relationship to the growth factor riboflavine. This was in accord with a new view in chemotherapy, first postulated by D. D. Woods in 1940 to explain the activity of sulphanilamide, and soon afterwards stated in a more general sense by P. Fildes, which regarded some therapeutic agents as acting on organismal disease incitants, for example bacteria, by inhibiting the use of chemical factors essential for their growth or multiplication. This view nearly always seemed to imply a structural similarity between growth factor and inhibitor. Comparison of 2666 with the formula of riboflavine (IV) did indicate a slight formal resemblance between the two, and subsequently a biochemical investigation proved that, at any rate with respect to the growth of the organism *Lactobacillus casei*, these two compounds were antagonistic to one another. This was sufficient to warrant a research designed to enhance the antagonism, but, despite the preparation of a great many compounds, no material advance was made along these lines in improving the antimalarial action of 2666.

A second hypothesis was concerned with the tautomeric possibilities shown by the active structures, and, as events turned out, it was the development of this hypothesis which ultimately led to Paludrine. Schönhofer (the discoverer of pamaquin) had pointed out that the central nucleus of mepacrine was capable of undergoing tautomeric change through migration of the hydrogen atom of the 5-imino group to the ring nitrogen atom, giving the *p*-quinonoid arrangement of bonds seen in (V). A similar arrangement was possible in the 2666 molecule (VI), and indeed closer examination of the molecule showed that no fewer than six tautomeric structures could be formulated. Some of them, for example (VII), were *o*-quinonoid in type. Several months after 2666 came



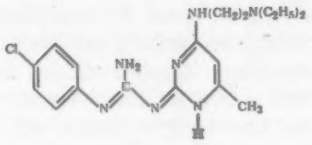
(V) (VI) (VII)

3349, which closely resembled the former but differed from it in having a guanidine group joining the benzene and pyrimidine nuclei. The introduction of this group still further increased the total number of tautomeric possibilities in the molecule. This was paralleled by an enhancement of antimalarial activity in the chick, and the discovery, for the first time in the new series, of an antimalarial action in man. Then another important observation was made. The two isomers of 2666, (VIII) and (IX), in which the groups attached to the pyrimidine ring were transposed, were found to be active and inactive respectively. When the tautomerism of these structures was analysed, it was seen that fewer possibilities existed for (IX) than for 2666, 3349, or (VIII). Moreover, the tautomers differed qualitatively from those of the active structures. In the latter group it was possible with each substance to formulate the molecule in such a way that the benzene ring and the basic side chain were linked through a conjugated system made up of alternate carbon and nitrogen atoms. Structure (VII) shows this in the case of 2666, and (X) the similar arrangement for 3349. In no way was

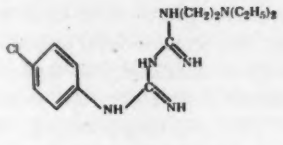


(3349) (VIII) (IX)

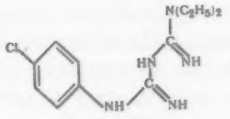
it possible to fit the inactive (IX) into the same picture. Here, it was suggested, was the secret of antimalarial activity in this particular type of chemical substance. That being so, it followed that a central ring was not an essential component, and that any related system providing the necessary alternation of nitrogen and carbon atoms with the appropriate double bonds might be antimalarial. The simplest molecular type conforming to these conditions was that of the biguanides, and compound (XI), formulated in an unconventional manner to show its relation to 2666, was



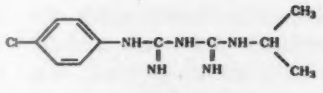
(X)



(XI)



(3936)



Paludrine (*base*)

prepared. This compound was inactive in the chick. It was, however, a much stronger base than 2666, and to make it more equivalent to the latter in this respect, part of the basic side chain was omitted and the new compound, 3936, synthesized. Activity then reappeared, and in a much wider sense, since for the first time an action against the exo-erythrocytic forms of the parasite in the chick was found. This held out the hope that substances of the biguanide class might function not only as suppressants but as causal prophylactics. The next step was to vary the 3936 molecule to see if a more effective compound would result. In November 1944, Paludrine was synthesized and proved the most active of the biguanide antimalarials. It is administered by mouth as the colourless hydrochloride, and in the chick and other experimental species it is many times as effective as mepacrine or quinine, with a much wider range of activity. Not only does it destroy the malaria parasites in the blood of the birds, but when administered at the correct time it even prevents the infection from developing. In man it is well tolerated; doses up to 1·5 gm. a day have been given, while as little as 10 mg. a day gives an action in the clinical phase of malaria. In addition it seems likely that the promise shown in the chick test will be paralleled in man, and that some measure of control of the disease will be possible from the time of infection by the mosquito. Preliminary results have indicated that it may be a true causal prophylactic in malignant tertian malaria, and a partial causal prophylactic in benign tertian malaria.

However, much still remains to be done before the final answer is known and the place of Paludrine in the armamentarium of tropical medicine defined; but at its lowest valuation it introduces a new chemical type into the chemotherapy of malaria, capable of considerable further exploration by biologist and chemist alike.

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Science in society: the fundamentals

E. F. CALDIN

Much recent writing on the social functions of science has been so coloured by political prejudice as to be of little value. In this very thoughtful article Mr Caldin has avoided this pitfall without evading the fundamental issues. He presses the claim, so well established but so often ignored, for the recognition of science as a source of truth as well as a means of improving the lot of mankind. Scientists should here find much food for reflection.

At this time, when a great expansion of scientific research in Britain is being planned, it is of unusual importance that the fundamental values of science should be well understood, so that the right men may be recruited and the right atmosphere maintained. The starting-point is the recognition that science has two aspects: (*a*) it is a source of knowledge, and (*b*) it can be applied to change material conditions. The present prestige of science is mainly due to its success in the latter role, but for its healthy development the former should be appreciated. A discussion of the significance of science as a source of truth is a pressing need.

This discussion is not made easier by the prevalence of a confusion between science and its application: between the understanding of nature and the manipulation of it for economic purposes. The confusion is not without excuse, because in the industrial organization of British economic life, and still more in the war-time mobilization of scientists, a large proportion of the men who leave universities with a training in science must bend their knowledge of nature to the control of matter to fulfil some technical requirement. But this is one of those occasions when a small mistake at the beginning is a grave error at the end; lack of clear distinctions at the start leads to a distorted conception of the place of science in society. Most of those who deal with this topic are really thinking of the place of technics in society, and of science only in relation to technics. It is necessary therefore to start by formulating some essential distinctions and elucidating their rational basis.

We may distinguish three main fields in which a man with a training in science may find himself working: (*i*) pure science, (*ii*) applied science, and (*iii*) technology. 'Pure science' denotes the study of nature for the sake of the good resulting simply from the understanding of nature, apart from any material benefits. Its method is to experiment (or observe) and then to interpret the results in terms of some hypothesis which, even though temporary, confers some degree of understanding. 'Applied science' uses the same method and arrives at the same sort of knowledge; but the knowledge is sought primarily for the sake of its applications. Between pure science and applied science there are many affinities. The material they work on is the same; the scientific methods used are the same; the theses produced are similar; there may be close contact between workers in the two fields. Moreover, men working on applied science may themselves be more interested in the knowledge gained than in its application, and may have as good an understanding of nature as their academic counterparts. No distinction can be drawn between pure and applied science in terms of differences in the training or competence of workers; or in organization; or in method, which in both studies is simply that of natural science; or even in the immediate outcome of the work, which for both is a new understanding of nature. None the less there is a difference, which is not at all subtle, between the general outlooks of men representative of pure science and of applied science; and the reason for it is to be found in the difference of the ends which are served by the two types of work. The end served by the study of pure science is the growth of mankind in the good attainable through merely understanding the world; that is, the advance in truth and goodness which is possible for men who study nature through science. The end served by applied science is the control of nature, its manipulation for the material welfare of men. The distinction of these ends corresponds to the distinction of the speculative and practical functions of the mind.

This difference of ends is not a sterile distinction. It corresponds to a very considerable difference in outlook on the part of the scientists

concerned; to a difference of orientation in the choice of subjects for investigation, and in the emphases adopted in exposition; and ultimately to differences of opinion about the directions which 'fundamental research' should take—whether it should follow the inner logic of the knowledge gained, or should investigate systems of possible technical importance. The difference of ends also distinguishes technology from science. Technology is the application of the knowledge won by pure or applied science, in working out and practising techniques for the control of material nature; and whereas scientific research is concerned with winning and organizing knowledge, technological research is concerned with the application of that knowledge for extra-scientific purposes.

Some people—even some men of science—have had difficulty in finding the basis of the distinction between technology and the sciences. There are indeed considerable affinities between them. They both deal with the material world and with the same kind of knowledge about it; they both use experimental methods in research; they both employ men trained in science; they use similar vocabularies. Technology depends upon science for the knowledge which it applies, and sometimes provides the raw material of scientific advance, namely new observations or other stimulants to investigation. No distinction can indeed be made in terms of subject-matter, training of personnel, or terminology; nor, as things are, could the actual study of science easily be separated from technology, on which it has come to depend rather intimately for materials and apparatus. Yet it is impossible to maintain that science and technology are one and undivided without depriving distinctions of their meaning. The first distinction is again that of ends; the whole of the preceding discussion on applied science holds good for technology also, and the resulting differences of personal outlook and of the organization of work are even more marked. For instance, a technologist's problem is assigned to him and he is expected to provide a solution; whereas in science it is essential that there should be some freedom of investigation. A second distinction concerns method. The method of modern technological research consists in applying the results of science as far as possible and, where they are insufficient, conducting *ad hoc* experiments. If the system concerned is simple enough, and if the relevant scientific work has progressed far enough, it is only necessary to verify a result predicted on scientific grounds. But it often happens that too many unknown factors are involved, or that scientific data are not available over a sufficient range, or that several phenomena are concerned simultaneously; for these or other reasons it may be necessary to try various expedients until one is successful.

In such experimental investigations there are several important analogies with the experiments of science: variable factors are controlled, and the correlation of variables is employed. But the method as a whole differs radically from that of science. The experimental part of science, being directed towards understanding the system under investigation, is essentially connected with the other part of scientific method, namely, the formulation of explanatory hypotheses; an experiment which leads to no new understanding is a failure, and experiments are commonly designed in the light of some hypothesis in order to verify it or disprove it. The experimental part of technology, on the other hand, except in so far as it makes use of knowledge already won by science, uses simply the method of trial and error; it does not as such lead to any new understanding of nature. Technology is usually content to tabulate observations in a form convenient for achieving certain specific practical aims; it does not seek to understand the relations between the observations. Technology presupposes scientific understanding, but does not normally contribute to it. Tables of quantitative data, however extensive and accurate, do not constitute scientific knowledge, though they may be raw material for the scientist. A third distinction is the restriction in technology of the field of interest; many phenomena of great scientific interest are useless to technology and are ignored by it—eclipses, for example, and earthquakes.

With these differences of aim, method, and field of interest in mind, it does not seem possible to maintain (as some would like to maintain) that science and technology are indistinguishable as well as indivisible. Much of the current writing on the place of science in the post-war world is really about technology, with science considered only as part of the necessary basis for it. That technology will be of major importance to Britain, no one will deny; but the question of the place of technics in society raises wholly different problems from that of the place of science in society. Moreover, scientists have special qualifications to deal with the second question, but with regard to the first they can speak only as citizens. It is with the second that the rest of this study is concerned.

The important problems for scientists and others with some education in science concern its influence on their thought and practical life, and hence on their fellow-men. For life is a unity; the scientific part of life affects the rest; a scientist becomes, in and through his scientific work, a better man or a worse; and his influence on his fellow-men is correspondingly helpful or harmful. It is therefore important to understand how science ought to be integrated with the rest of a scientist's life, and how this bears on his social influence.

The key to this integration is that scientific life is a version of rational life, an adaptation to a particular activity of the principles common to all rational life; consequently, if rightly lived, it should develop those qualities which make rational living possible in other departments of life. Scientific life is a type of life lived according to right reason. First, it demands the experience of the senses; not haphazard experience and hearsay evidence, but careful observation and intelligent searching; a mind alert for novelty but trained also in cautious verification. Second, it demands that observation shall be interpreted by reason, which brings order into the data of sense; it requires rigorous logic, controlled imagination, intellectual insight, clear analysis, and wide synthesis. It requires that we learn about nature from experience (as distinct from spinning myths) and that we interpret that experience by reason (as distinct from merely remembering or applying it). Third, it is characterized by a continual interplay of experiment and theory; experiments suggest hypotheses, hypotheses in turn suggest experiments which may verify them. Scientific life, then, requires a rational unity of thought and action. Fourth, it is a developing tradition: neither a code of unalterable rules, nor, on the other hand, a formless collection of varying authenticity, devoid of established criteria for judging new developments. That is, the scientific spirit will tolerate neither a sterile immobility nor a rootless fickleness; scientific beliefs need periodic overhaul and constant adjustment. Fifth, as a consequence, scientific life requires freedom: freedom of thought, of discussion, of publication, and of investigation. Sixth, scientific work is a social as well as a personal enterprise. All scientists must take on trust a vast body of facts established by their colleagues and predecessors, and it seldom happens that any important field of scientific investigation is monopolized for long by one man. Consequently, the practice of science requires both personal integrity and respect for one's colleagues; tolerance for others' opinions, and determination to improve one's own; and care not to overstate one's case or to underrate that of others. Thus a mental 'climate' is favoured which is a balance of appreciation and criticism.

All the six general principles named belong also to other studies and indeed to any rationally conducted enterprise, from philosophical research to farming. Every student can recognize in them the principles of his own speciality. But in pursuing natural science we use a special adaptation of those principles, a particular version of rational method. Historians use another version, philosophers yet another; craftsmen, business men, housewives, all have their own special rational habits adapted to the work in hand. The method of natural science is not the sole and universal rational way of reaching truth; it is one version of rational method, adapted to a particular set of truths. The point needs emphasizing, both to point out a common mistake and to show how to correct it. Large numbers of people have been misled into thinking that the procedure of natural science is the royal road to truth in every field; that what cannot be proved by science cannot be true; and that metaphysical propositions, for example, are meaningless or at any rate unprovable. The mistake here lies in confusing the part with the whole—scientific method with rational method. But we can substitute an important truth for the mistake if, agreeing that science is not to be divorced from other rational pursuits, we find their connection in this: that science is not only a version but a microcosm of rational life. By this is meant that in studying science and becoming familiar with that form of rational activity, one is led to understand rational life in general: one grasps the principles of all rational procedure through practice of one form of it. It should then be easier to adapt those principles to other studies and to life in general. Scientific work, in short, should be a school of rational life.

In parenthesis, it may be remarked that one of the greatest needs of contemporary scientific and intellectual life is a clearer understanding of the relations and differences between the methods of natural science, philosophy, history, literature, and so on. It is time to develop the comparative study of rational methods, a field in which work has been piecemeal and scattered. We need a survey which will show exactly how the diverse methods of the various rational disciplines are all

versions of the general method of reason working on experience, and yet are all legitimately different. A constructive account such as this could do much to reduce the intellectual malaise of our time, which cries out for a synthesis. Lacking one, there is a tendency to erect general systems on partial aspects of the whole—treating, for example, the economic element in social history as a sufficient basis for the interpretation of history; or, at best, resting content with very inadequate accounts of the relations between rational disciplines—distinguishing science and philosophy, for example, in terms of some facile distinction of objective and subjective or realist and idealist. Endless confusion would be saved if it were more widely realized that natural science is restricted, by its very method, to the study of a limited field from a particular angle, and has nothing to say (for example) about the principles of ethics, or the freedom of the will; these are dealt with by philosophy, with its wider field, more generalized approach, and correspondingly different methods. Scientific life can be a microcosm of rational life, but it cannot claim to be the macrocosm.

These views may be applied to the question of the 'social function of science.' There are in fact two quite distinct (though not separable) ways in which scientists as such discharge their responsibilities to their fellow-men. One is through the application of science to make easier the material conditions of life. But the ease and frequency with which science is misapplied make this quite inadequate as a justification for the existence of science. A much stronger case can be made for science as a social force in terms of its approach to truth than in terms of its usefulness. Those whose work is primarily concerned with science itself, whether in teaching or research, can fulfil a highly important social function simply by their living devotion to the conservation, advance, and propagation of scientific life. For if science can be made a real school of rational life, in virtue of its being a type and microcosm of rational procedure, it must necessarily contribute to the personal development of those who follow it.

Anyone who has seen the general intellectual development which can result from the proper teaching of science at a university must admit that the academic scientist can contribute not a little to the personal growth of young people. Society at large benefits from such personal development; for its vitality depends upon the vitality of individual people and their intellectual and moral ideals. Again, it will probably be agreed that the fundamental values of reason, and in particular the value of truth and the dignity of the human person, stand in great need of buttressing. It may be that natural science will be one of their supports, for science has an advantage over history, or philosophy, or literature, as a representative of reason, in that so long as it remains alive at all, it cannot be wholly false to the true rational spirit. False science is easily disproved, by experiments reproducible at will; moreover, it would fail if attempts were made to apply it. No one can coerce nature; it cannot be persuaded by the will or affected by the imagination, whereas most other studies are liable to perversions which are much more difficult to eliminate and may greatly weaken the work of whole schools of thought and generations of scholars. At all events, while the prestige of science stands so high in the common estimation, scientists have a special responsibility to uphold reason in science and in general.

The application of this line of thought to the question of the 'planning of science' may be briefly suggested. Planning in science and planning the application of science are two different things. Research in technology, and to some extent in applied science also, is fittingly directed towards solving problems indicated by some outside authority—the problems of health or of national defence, for example. But since the end of pure science is knowledge, rather than use, it must follow its own inner dialectic and cannot be directed by any authority external to itself; moreover, as is often pointed out, any attempt at external direction is fatal to the quality of the work produced. The part of external authorities is to provide facilities rather than to apply compulsion. The same applies to the planning of science from within: projects for allotting work and preventing overlapping by compulsion are not in the true spirit of science.

In this short exposition of the primary function of science, the attempt has been made to retain what was positive in the older apologia of science, which represented its value as due to its loyalty to truth, and to complete it by re-stating it in terms of personal life and the good of persons. At the same time the view outlined cannot be accused of favouring a selfish or irresponsible attitude. No apology is made for dwelling upon fundamental truths which may seem trite to many; for these truths should be the presuppositions of practical decisions, and if they are replaced by false presuppositions the consequences may be grave indeed.

Cosmic rays and their origin

A. C. B. LOVELL

It is now generally accepted that the cosmic radiation at sea level consists mainly of two components—the soft component composed of electrons, positrons, and photons, and the hard penetrating component chiefly composed of mesons. Is is also generally believed that these two components arise mainly as a result of secondary processes in the earth's atmosphere. This article gives a brief description of recent work and of previous experiments.

THE ELECTRON COMPONENT OF COSMIC RAYS

The intensity of the cosmic ray electrons at sea level is about 0·3 electrons per sq. cm. per minute, very nearly equally divided between positive and negative electrons. This represents about one-third of the total number of ionizing cosmic ray particles found at sea level. The distribution of energy in these electrons has been measured up to about 2×10^{10} electron-volts (eV) and varies inversely as the square of the energy (E). It is believed that this inverse square law extends to considerably higher energies. The upper limit of the energy range is not yet known but it is certainly more than 10^{15} eV and may be over 10^{20} eV.

THE CASCADE PROCESS OF MULTIPLICATION

The application by Bethe and Heitler [1] of quantum mechanics to describe the behaviour of an electron in its passage through matter indicated that when an electron of high energy passes through matter it loses energy in two ways:

(*a*) By collision with extranuclear electrons of the atoms through which it passes. If sufficient energy is communicated in the collision the electron may be removed and the atom ionized, otherwise the atom may be raised to an excited state and emit a photon.

(*b*) If the electron passes close to the nucleus of the atom it comes under the influence of strong electric fields and is subject to large accelerations. It then loses energy by radiation (production of photons).

The subsequent application of this Bethe-Heitler theory to the study of cosmic rays by Bhabha and Heitler [2] and also by Carlson and Oppenheimer [3], in 1937, gave a satisfactory explanation of one of the most frequently observed phenomena in cosmic rays, namely the occurrence of showers, or simultaneous groups of electrons. This method of shower production is known as the *cascade process* and is illustrated diagrammatically in figure 1.

The incident electron passes close to the nucleus of an atom at α and a photon is radiated, which subsequently passes close to the nucleus of another atom at β, and produces a pair of positive and negative electrons. Meanwhile the original electron produces another photon at γ, which in turn produces an electron pair at δ. So the process continues and the system loses energy at an increasing rate. If, in its path, the shower encounters a sufficiently large number of atoms, the process of subdivision reaches a maximum, after which the energy of the electrons is so low that they become absorbed without production of further particles. The thickness of material necessary to give this maximum number of particles is predicted by the cascade theory. It increases as the energy of the original electron increases.

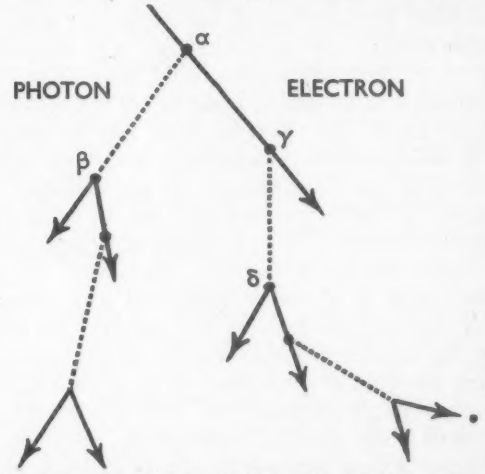


FIGURE 1 – *Diagrammatic illustration of the cascade process of shower production.*

Figure 3 shows a cloud-chamber photograph

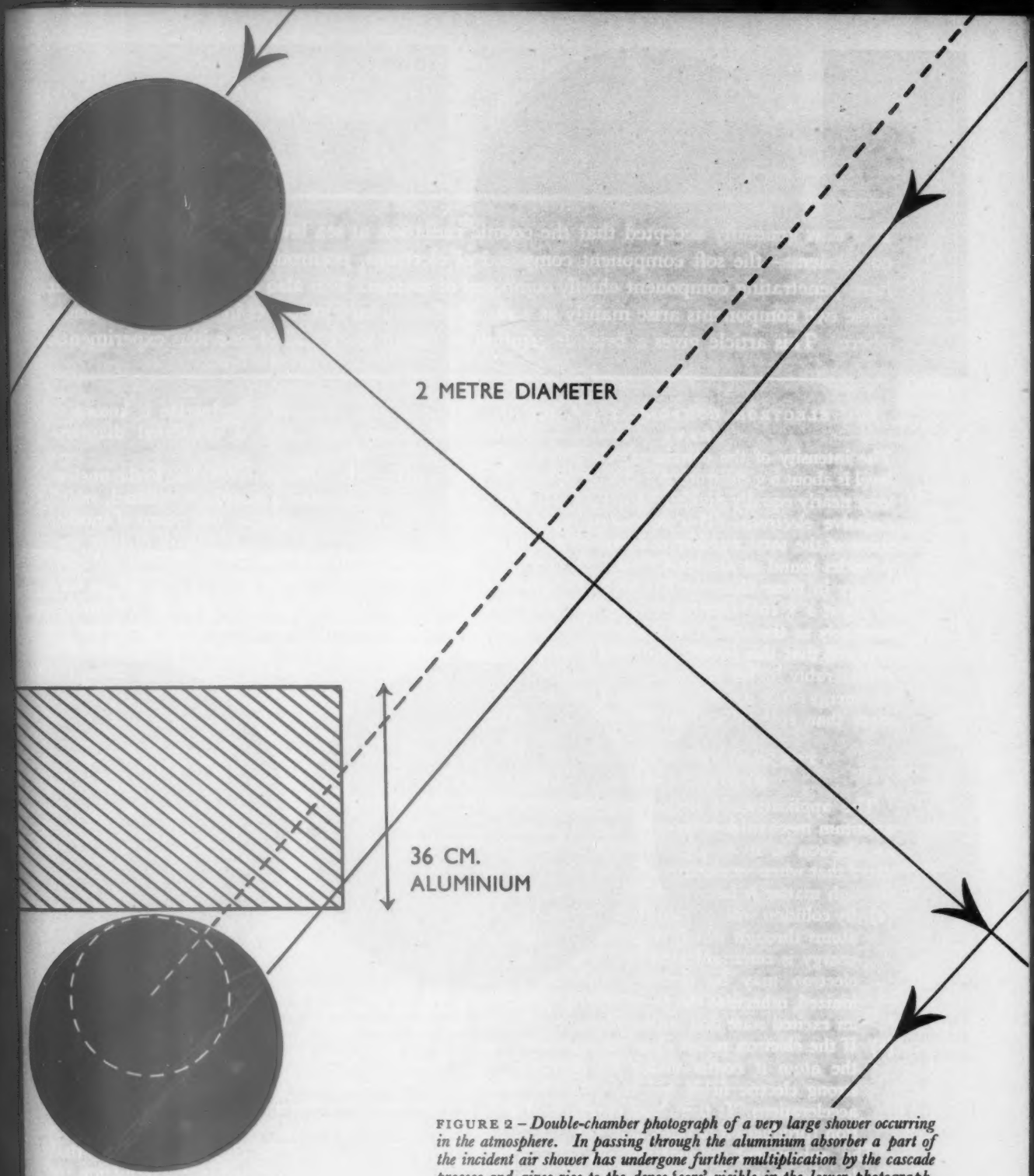


FIGURE 2 – *Double-chamber photograph of a very large shower occurring in the atmosphere. In passing through the aluminium absorber a part of the incident air shower has undergone further multiplication by the cascade process and gives rise to the dense 'core' visible in the lower photograph. These photographs were obtained with the apparatus shown in figure* 5 *and the reproduction is to scale except in the case of the two actual photographs which are* × 2 *scale. The centre line indicates the estimated direction of the particles in the air shower which gave rise to the dense core. The asymmetry in the scale has made this line pass much closer to the edge of the aluminium than it should do. (The actual position of the lower chamber and the location of this line through the aluminium are shown in dotted line.) It was estimated that the main part of the shower occurred in a cylinder of about* 2 *metres diameter as indicated by the outer lines and probably contained some* 50,000 *particles of exceedingly high energy.*
(Photograph by Dr J. G. Wilson and the Author.)

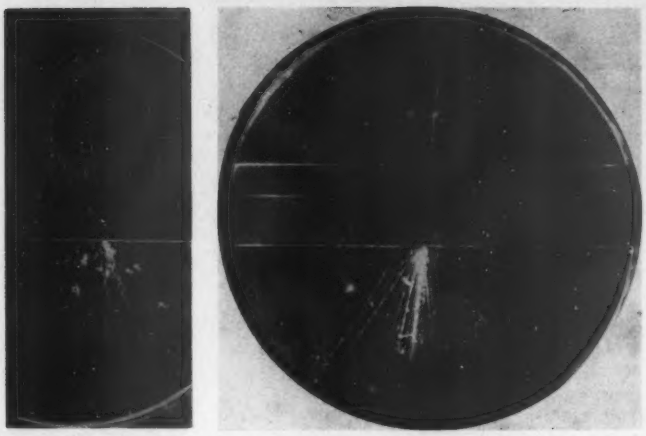
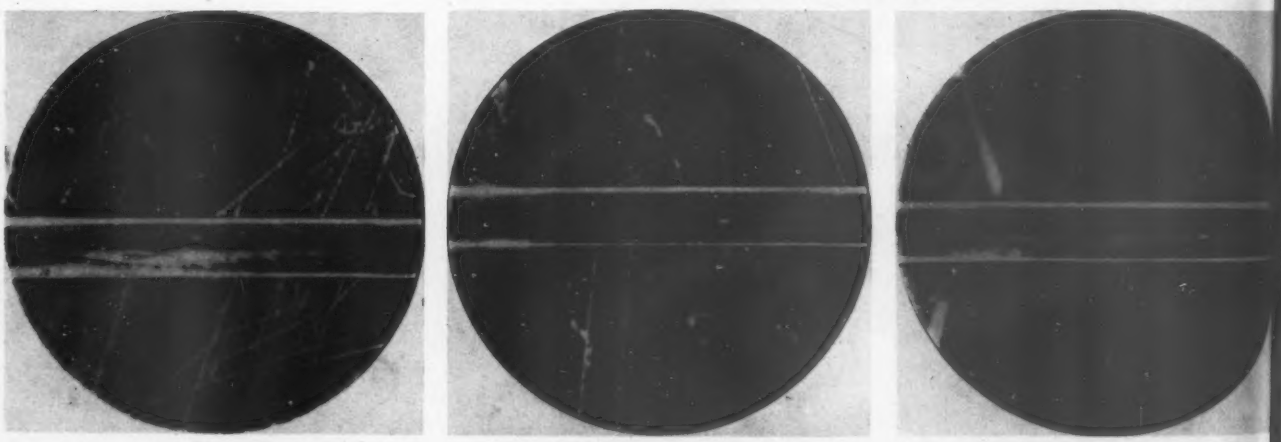


FIGURE 3 (*left*) – *A typical cascade shower of electrons and positrons. The cloud chamber was in a magnetic field of* 10,000 *gauss and the momentum of the particles was measured from the curvature of their tracks.*
(*Photograph by Dr J. G. Wilson.*)

FIGURE 4 (*top centre*) – *Cloud-chamber photograph of a 'knock-on' shower. The particle in the top half has already traversed* 20 *cm. of lead and is a meson. It produces a shower of electrons and positrons in the lead plate across the centre of the chamber. (The lead plate was* 1·8 *cm. thick but a metal box containing a Geiger counter rested on top of it.)*
(*Photograph by the Author.*)

FIGURE 5 – *Two cloud chambers, mounted vertically one above the other, separated by* 36 *cm. of aluminium, which photographed the very big cosmic ray shower shown in figure* 2. *The lower chamber was working in a magnetic field of* 1,000 *gauss. A part of the cooling fan is visible on the extreme left of the photograph.*



FIGURES 6, 7, 8 – *Examples of cloud-chamber photographs obtained with the apparatus illustrated in figure* 10. *These particles must have penetrated* 53 *cm. of lead in order to have operated the chamber. Moreover they pass through a* 2 *cm. lead plate in the chamber without multiplication which proves them to be mesons.*
(*Photographs by Dr Rochester.*)

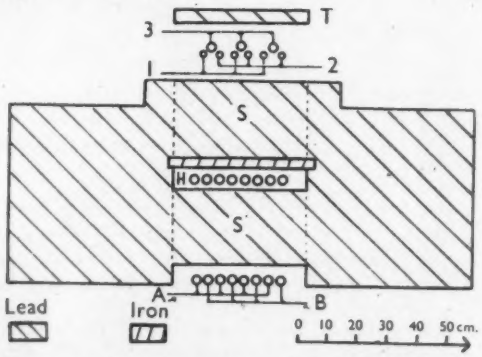


FIGURE 9 – *The counter apparatus used by Jánossy and Ingleby to prove the existence of showers of mesons. The weight of lead used in the experiment was* 15 *tons.*

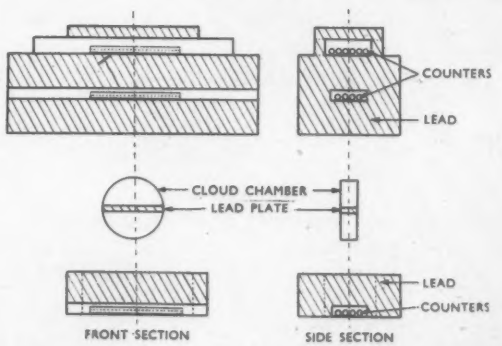


FIGURE 10–*Arrangement of counter-controlled cloud chamber used by Rochester to photograph showers of mesons. The total vertical thickness of lead was* 53 *cm.*

of a characteristic electron cascade shower of this type. The particles in the top half of the photograph are positive and negative electrons with energies of from 5×10^7 eV to 4×10^8 eV. These are part of a cascade shower starting outside the cloud chamber, probably in the atmosphere. On passing through a 2 cm. gold plate across the centre of the chamber they multiply still further by the cascade process.

Although the quanta and secondary electrons produced by such processes will be projected in the general direction of the incident electron, it is obvious that if the original electron has a very high energy a large number of secondary particles will be produced in the shower, which may eventually spread out to cover a considerable area. The existence of exceedingly large showers in the atmosphere was first shown by Auger and his collaborators in 1939 [4]. They found coincidences in Geiger counters which were separated by distances up to 300 metres. In the same year, Lovell and Wilson [5] obtained cloud-chamber photographs of a portion of these big showers originating in the atmosphere by using two cloud chambers separated by distances of up to 20 metres, and also with one chamber mounted vertically above another.

These chambers were counter-controlled in such a way that photographs were taken only when a large number of electrons passed through both chambers simultaneously. Figure 2 is a scale photograph of one of the big showers obtained. This shower contained at least 50,000 particles; such extensive showers occur very infrequently.

Figure 5 shows a photograph of the double chamber apparatus with which this shower was observed. Such big showers occur very infrequently.

THE ORIGIN OF THE COSMIC RAY ELECTRONS

The cascade theory does not touch the question of the origin of the incident electron responsible for initiating the shower. With the possible exception of some of the very extensive air showers, the electrons found at sea level cannot be the direct result of primary electrons incident from space on the earth's atmosphere, since (except for those with very high energies) the range of the primaries would not be great enough. It is now known, however, that two other processes capable of producing electrons or electron showers can account satisfactorily for the electron component of cosmic rays found at sea level. These are (i) the decay of the meson into an electron, and (ii) the production of cascade electron showers by the *knock-on process* from mesons.

Meson Decay. In 1937, Anderson and Neddermeyer [6] obtained evidence that particles of mass intermediate between the mass of the electron and proton were present in cosmic rays, and it soon became evident that these particles were in fact mainly responsible for the so-called hard or penetrating component of cosmic rays. The mass of these 'mesons' is now believed to be about 180 times the electron mass, and they possess the same charge as the electron (positive or negative). Such a particle was postulated by Yukawa [7] in 1935 in order to explain the forces inside the atomic nucleus. Yukawa's theory also postulated that this particle should 'decay' spontaneously into an electron and a neutrino, and that it would have an average lifetime of about 10^{-7} second.

Experimental evidence that the cosmic ray mesons did in fact decay was soon obtained. For example, it was found that the absorption of the mesons differed for equivalent masses of heavy materials and air, and this can be explained only if in addition to an absorption dependent on mass, there is an independent spontaneous loss of particles increasing with the path traversed. The average lifetime for a meson at rest is found experimentally to be 2×10^{-6} second, in reasonable agreement with Yukawa's prediction. More direct evidence of the decay of the meson was secured in 1940 by Williams and Roberts [8], who obtained a cloud-chamber photograph of a meson stopping in the gas of the cloud chamber and an electron emerging from the end of the meson track.

The decay of the meson is, therefore, one process which gives rise to cosmic ray electrons. Moreover, if the meson decays when it possesses considerable kinetic energy, the decay electron will also be of high energy and hence will give rise to cascade showers of electrons as described above.

Knock-on Showers. The two main processes by which an electron loses energy when it passes through matter have already been discussed. In the case of mesons, quantum theory predicts that the main process of energy-loss is by collision with extranuclear electrons which are 'knocked-on' and are then able to produce a cascade shower of electrons.

This knock-on process is responsible for the electron component found under large thicknesses of lead and deep underground. The process can be demonstrated in cloud-chamber experiments by

working under say 20 cm. of lead. The probability that a high energy electron may traverse such a thickness and emerges as a single particle without producing a shower is negligible. Hence most single particles appearing beneath the lead will be mesons. If these are now photographed in a cloud chamber with a lead plate across its centre, they occasionally produce showers in the plate. For example, figure 4 shows a single particle in the top half of a cloud chamber which has already penetrated 20 cm. of lead and is therefore a meson. In passing through the lead plate in the chamber it knocks-on an electron which then produces an ordinary cascade shower. The number and size of such showers found with such an arrangement agree well with theoretical calculations based on the above mechanism.

THE ORIGIN OF THE MESONS

It is now believed that the processes of meson decay and knock-on of electrons by mesons can provide an explanation of the number of cosmic ray electrons found at sea level. The fact that the mesons decay spontaneously with an average lifetime of about 10^{-6} seconds means that they must be created near the earth. Assuming that they are created in the earth's atmosphere, the most vital questions are: what are the primary particles? and how are the mesons created, singly, in pairs (positive and negative), or as showers of many simultaneous mesons? The greatest uncertainty prevailed on these points up to the outbreak of war. Some workers claimed to have proved the existence of showers of mesons, and in 1939 Braddick and Hensby [9] obtained a convincing cloud-chamber photograph of a pair of mesons. The work carried out in Manchester during the war by Jánossy, Rochester, and their co-workers probably settled the question.

Counter Experiments. The first proof of the existence of showers of penetrating particles was obtained by Jánossy and Ingleby [10] using a counter apparatus illustrated diagrammatically in figure 9. A similar experiment was carried out independently by Wataghin and his co-workers [11] in Brazil.

This apparatus worked by recording *five-fold coincidences* 1–2–3–A–B, and evidence as to the numbers of particles involved in such a coincidence was given by the eight counters H which controlled small neon indicators. The results could be interpreted only on the assumption that the showers causing the coincidences were composed of associated penetrating particles. Moreover the results with and without the absorber T showed that less than half of the penetrating showers come from the atmosphere, whilst the rest are produced in the absorber.

Further experiments of this type by Jánossy and Rochester [12] during the period 1940 to 1943 gave the following additional information:

(*a*) Some of the penetrating showers extend over a large area.

(*b*) About one-third of the penetrating showers are produced by a non-ionizing radiation more penetrating than photons (probably neutrons).

Cloud-chamber Experiments. In 1944 Rochester [13] obtained 30 photographs with a counter controlled chamber arranged as in figure 10.

The chamber was operated by a sevenfold coincidence, which meant that about 95 per cent. of the coincidences were caused by penetrating showers. Eighteen photographs showed particles passing through a 2·3 cm. lead plate inside the chamber without multiplication (proving them to be mesons) and nine of the eighteen photographs showed showers of two or more particles. Examples of these photographs are shown in figures 6, 7, and 8; they demonstrate beyond doubt the existence of associated penetrating particles.

The Theory of the Origin of Mesons. The theory of the origin of mesons suggested by Hamilton, Heitler, and Peng [14] appears to be the most likely explanation of the results of the above experiments. In this theory the incident particles are considered to be protons. A single meson is the result of an inelastic collision of such a proton with a proton or neutron, while a shower of mesons is the result of a collision of the incident proton with an atomic nucleus containing several protons. At the time of writing, Heitler and his co-workers at the Dublin Institute for Advanced Studies are still working on this problem, and it is not yet certain if protons incident at the top of the atmosphere can alone explain the ultimate production of the soft component at sea level, or whether it is necessary to invoke the presence of very high energy electrons in the incident beam to account for the extensive air showers found at sea level.

THE ORIGIN OF THE COSMIC RAY PARTICLES INCIDENT ON THE EARTH'S ATMOSPHERE

Recent experiments and theoretical developments give some evidence that the cosmic ray particles incident on the earth's atmosphere may be protons. There is, however, no scientific

evidence as to how these particles originate or where they come from. There have, of course, been many speculations, such as that they originate in the building up or annihilation of matter in interstellar space, but the extent of our scientific knowledge is that the intensity with which they bombard the earth's atmosphere is about thirty particles/sq. cm./minute, and that the average energy of the particles is about 6×10^9 eV. The energy which these primary rays bring to the earth is therefore $1{\cdot}8 \times 10^{11}$ eV/sq. cm./min. Taking the radius of the earth as approximately 4,000 miles this represents a total energy flow of $1{\cdot}5 \times 10^{18}$ ergs/min. over the whole surface of the atmosphere. But one horse-power is equivalent to $7{\cdot}46 \times 10^9$ ergs/secs.; hence the total energy of the primary rays is approximately $3{\cdot}4 \times 10^6$ h.p. This is comparable with the developed water-power resources of the world (3×10^7 h.p.). It is, however, minute compared with solar energy (5×10^{22} h.p.) of which 10^{14} h.p. reaches the surface of the earth.

THE "THIRD" COMPONENT OF COSMIC RAYS

Although electrons and photons (soft component) and mesons (hard component) together account for nearly all the cosmic ray particles found at sea level and in the lower atmosphere, there is in fact an almost vanishingly small third component. This represents only about 1/10,000 of the total cosmic ray intensity at sea level. It certainly contains positive protons, and there is a growing belief that it may also contain negative protons although none has yet been observed. It also contains neutrons or some neutral particle more penetrating than photons, otherwise the results of Jánossy and Rochester on the production of penetrating showers in an absorber at sea level cannot be explained.

FUTURE RESEARCH

Cosmic-ray research is fast becoming a technically difficult and expensive process. Thus, in order to verify experimentally the outstanding uncertainties described in this article it will be necessary to carry out laboratory experiments in the upper atmosphere, both to discover the nature of the incoming particles and the processes by which mesons are produced. Such experiments will involve manned balloon ascents into the stratosphere and high altitude work in aircraft with specially designed, lightweight, high-altitude cloud chamber and counter equipment. It may also need experiments in rockets of the V2 type. The extension of the measurement of the energy distribution in the rays at sea level to energies above 10^{10} eV will need the construction of a powerful magnet, and already in Manchester the construction of a magnetic spectrograph consisting of two 10,000-gauss magnets is being planned. Also in Manchester the possibility of detecting the big atmospheric air showers by using radar technique is being explored.

CONCLUSION

The particles incident from space on the earth's atmosphere are probably protons. In the upper layers of the atmosphere these produce positive and negative mesons singly and in showers by collisions with protons, neutrons, and atomic nuclei. The mesons produce electrons and photons (*a*) by decay into an electron and neutrino, (*b*) by 'knocking-on' an electron in a direct collision (the electron in both cases subsequently producing a shower by the cascade process). The intensity of the resultant cosmic ray beam at sea level is about one particle/sq. cm./minute, of which about one-third are electrons. Some of the very big extensive air showers may not be produced by these processes but may require the presence of some very high energy electrons (10^{15} to 10^{20} eV) in the incident proton beam. Protons and possibly neutrons are also found at sea level but these comprise only 1/10,000 of the cosmic ray intensity.

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Book reviews

NATURE AND USES OF COLLOIDS

Colloids. Their Properties and Applications, *by A. G. Ward. Pp.* 133. *Blackie & Son Limited, London.* 1945. 5*s. net.*

This admirable little book gives an extremely clear and well balanced account, for the non-specialist scientific reader, of the properties of colloids, the methods used in their investigation, and some of their principal applications in industry; biological applications are also dealt with, though less fully. It includes a brief but clear account of modern views on the atomic structure of matter and on the forces of cohesion in matter. Among the industrial colloids treated are rubber, including synthetic rubbers, natural and synthetic fibres, clays, paints, adhesives, etc. There is no attempt to enter into much detail, but the clear manner in which the organic and physical chemistry of these substances is set out, and related to their valuable properties, would be very difficult to surpass in so small a compass. The book is not intended as a detailed textbook; but it might well be put into the hands of a student about to begin the study of colloids, to provide him with a general view of the whole field. It is up to date, and looks forward as well as surveying what has already been done.

N. K. ADAM

WAVE MECHANICS FOR BEGINNERS

Elementary Wave Mechanics, *by W. Heitler. Pp. viii* + 136. *University Press, Oxford.* 1945. 7*s.* 6*d. net.*

Professor Heitler—now at the Institute of Advanced Study in Dublin—is well known as a distinguished contributor to the quantum theory of radiation; together with London he made the first really significant step in understanding the quantum theory of the chemical bond. As we should expect from his earlier book on radiation, his new book on elementary wave mechanics, originally given as a course of lectures to physics and chemistry students at Dublin, is very readable; indeed it is possible to sit down and read it through at a single sitting without feeling unduly tired. The book is intended for people with no previous knowledge of the subject and with no particular mathematical attainments. The actual mathematics is reduced to a minimum, but by a wise choice of method it is surprising how well it explains, or at least makes plausible, much of the more involved parts of the subject. It is refreshing to find a book that justifies its title of *elementary* without being trivial.

A book of 136 pages cannot possibly include everything, even in elementary wave mechanics. But it is hard not to regret the absence of any account of scattering problems, structure of the nucleus, metallic cohesion, harmonic oscillators and rotators, and selection rules, the majority of which contrive somehow to find a place in most elementary text-books. However, within the restricted framework set by the author, an extremely clear account has been given of the derivation and meaning of the Schrödinger wave equation, and of its application in the structure of an atom and the formation of molecules. What has been done is, with few exceptions, well done. It is a pity there was not more of it.

C. A. COULSON

X-RAYS IN THE STUDY OF METALS

An Introduction to X-ray Metallography, *by A. Taylor. Pp.* 400. *Chapman & Hall Limited, London.* 1945. 36*s. net.*

X-rays have found such important applications in the study of metals that some knowledge of the subject has become indispensable to every research worker in metallurgy. Dr Taylor's book admirably fulfils its purpose of describing the methods of applying X-ray methods to the study of metallic structures and of indicating the principal results obtained. Information is given which will enable the worker to select the best type of tube and of target for a particular task. An account is given of the way in which the arrangements of the atoms in a solid affects the X-ray pattern, of the means of determining phase boundaries in thermal equilibrium diagrams and of textures in mechanically deformed structures, and of the measurement of grain size. A final description is given of the use of X-rays in the examination of castings and forgings, a use not dependent on crystal structure. This includes a section on micro-radiography, using thin sections of alloys, a method which, it is often forgotten, was employed by Heycock soon after the discovery of X-rays, but which now seems to have no advantage over microscopical methods. As the theory of the subject is adequately explained and the methods are fully illustrated, the book should be invaluable to metallographers. Although it is produced in conformity with standards of economy imposed during the war, both printing and production are of high quality.

C. H. DESCH

FERTILIZERS: FOR AND AGAINST

Chemicals, Humus, and the Soil, *by Donald P. Hopkins. Pp.* 278. *Faber & Faber Limited, London.* 1945. 12*s.* 6*d. net.*

This is an admirable book. It examines the accusations of the pro-humus anti-fertilizer school in the clear, simple, and objective manner of an experienced judge putting the issues before the jury. The book is, in fact, a summing-up, for it is divided into two parts: I, the case for fertilizers; II, the case against fertilizers. Part I proceeds on conventional lines, and the mass of reliable scientific evidence is presented in very fair and restrained terms. It is in the handling of Part II that the author specially distinguishes himself. It would have been so easy to take the romantic exaggerations of the 'muck and mystery' school as the main target. Instead, the author concentrates his analysis on the statements of the sober-minded pro-humus writers. He has a difficult task, for some of them are—perhaps unconsciously — consummate guerilla tacticians, dodging from earthworms to the Cheshire doctors' 'Medical Testament,' from 'poisoned' crops to mycorrhiza, as one position after another becomes untenable, and sending suicide squads against Experiment Stations and statistical plot-techniques. But in Part II the author rounds them up, and shows convincingly that pro-humus evidence—and there is plenty—is not necessarily anti-fertilizer evidence. The conclusion is that humus and fertilizers are both jointly needed. They are complementary, not antagonistic; and, in any case, a wholly organic-manure civilization has been, for many years now, a stark impossibility.

B. A. KEEN

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Is Professor of Chemistry in the University of Edinburgh. He is just completing his tenth year of office as General Secretary of the Royal Society of Edinburgh, of the history of which he writes in the present issue. In the 163 years of the Society's existence there have been only eleven previous holders of that office. Like many others, Professor Kendall has found that the teaching and administrative responsibilities of a large department are incompatible with intensive original research and he has accordingly concentrated mainly upon his duty of 'communicating a knowledge of chemistry to the rising generation.' He was educated at Farnham Grammar School, the University of Edinburgh, and the Nobel Institute, Stockholm. From 1913–26 he held a chair of chemistry in Columbia University, New York. In the first world war he served in the United States Naval Reserve. Later he was Professor of Chemistry in Washington Square College, New York University.

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Was born in 1891 and was educated at Armstrong College (now King's College), University of Durham. He served with the Army throughout the first world war and was awarded the Military Cross in 1915. During part of this time he was engaged in research on the properties of organic arsenical gases. In 1919 he joined the staff of the Long Ashton Research Station, University of Bristol, as Research Chemist. He was appointed Deputy Director in 1924 and became Director in 1943, being elected to the Chair of Horticultural Chemistry in the University of Bristol. During his work at Long Ashton he has been interested primarily in the study of nutrition of fruit trees, involving studies of soils and of the chemistry and physiology of the hardy fruits. His methods of studying mineral nutrition were applied to vegetable and general crops during the recent war; and his book *The Diagnosis of Mineral Deficiencies in Plants* was published by His Majesty's Stationery Office in 1943. He has also published many technical papers on problems of plant nutrition. In 1934 he was awarded the Ridley Gold Medal of the Worshipful Company of Fruiterers.

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Was born in 1913 and was educated at the University of Bristol, graduating in 1934. For the following two years he worked at the H. H. Wills Physical Laboratory, Bristol, on problems relating to the conductivity of thin films of the alkali metals. In 1936 he was appointed Assistant Lecturer in Physics in the University of Manchester; and when Professor Blackett succeeded Sir William Bragg in the Chair of Physics at Manchester in 1937 he joined the former's research team investigating cosmic rays. On the outbreak of war he was appointed to the Telecommunication Research Establishment and played an important part in the development of short wave (centimetre) radar. From 1942 until the end of the war he was in charge of the application group working on blind bombing and anti-submarine equipment. In 1943 he was appointed Principal Scientific Officer of the Establishment. He returned to Manchester in July 1945, and has resumed his earlier work on cosmic rays, to the investigation of which he proposes to apply radar technique. He has published numerous technical papers and is also the author of two books on the social relationships of science, *Science and Civilization* and *World Power Resources and Social Development*. His present literary activities include the editing of a new series of scientific books and a large work on electronics.

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